Appendix B
Revetments

B-1. Quarrystone and Graded Riprap

a. General. Stone revetments are constructed either of nearly uniform size pieces (quarrystone) or of a gradation of sizes between upper or lower limits (riprap). Riprap revetments are somewhat more difficult to design and inspect because of the required close control of allowable gradations (pockets of small material must be excluded) and their tendency to be less stable under large waves. Economy can usually be obtained by matching the riprap design gradation limits to the local quarry-yield gradation, provided the disparity is not too great. Graded riprap revetments should be used with caution, but they are acceptable for low energy shore protection applications. Uniform quarrystone structures, being more stable, are recommended for high energy waves.

b. Advantages and disadvantages. The primary advantage of rubble revetments is their flexibility, which allows them to settle into the underlying soil or experience minor damage yet still function. Because of their rough surface, they also experience less wave runup and overtopping than smooth-faced structures. A primary disadvantage is that stone placement generally requires heavy equipment.

c. Design considerations. In most cases, the steepest recommended slope is 1 on 2. Fill material should be added where needed to achieve a uniform slope, but it should be free of large stones and debris and should be firmly compacted before revetment construction proceeds. Allowance should be made for conditions other than waves such as floating ice, logs, and other debris. Current velocities may also be important in some areas such as within tidal inlets where wave heights are low. Properly sized filter layers should be provided to prevent the loss of slope material through voids in the revetment stone. If using filter cloth, an intermediate layer of smaller stone below the armor layer may be needed to distribute the load and prevent rupture of the cloth. Economic evaluation of rock revetments should include consideration of trade-offs that result between flatter slopes and smaller stone weights and the increased costs for excavation that usually result for flatter slopes.

d. Design factors.

(1) Zero-damage wave height is a function of stone weight.

(2) Wave runup potential is estimated to be as low as 50 percent of smooth slope runup.

(3) Wave reflection potential is estimated to be low.

e. Prototype installations (Figures B-1 and B-2). Rock revetments are commonly found throughout the United States with good examples existing in almost all coastal locations.

Figure B-1. Quarrystone revetment at Tawas Point, MI

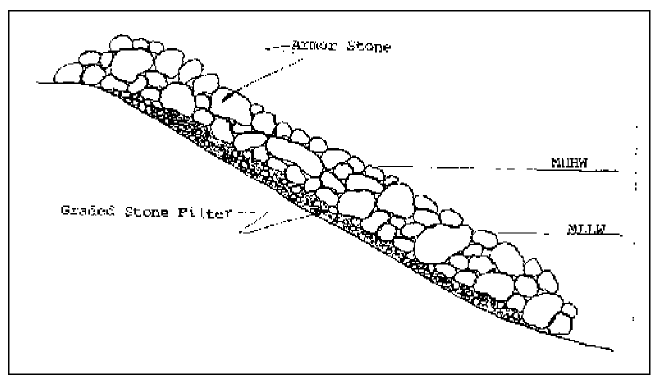


Figure B-2. Quarrystone revetment cross section

B-2. Rock Overlay

a. General. A rock overlay consists of a layer of large quarrystone used either to upgrade a damaged or undersized stone revetment or to provide economical initial design. Large-scale model tests (McCartney and Ahrens 1976) suggest that stability of such overlays is about equal to a standard design but with only about one-half the reserve strength.

b. Design factors.

(1) Zero-damage wave height is a function of stone weight.

(2) Wave runup potential is estimated to be as low as 50 percent of smooth slope runup.

(3) Wave reflection is expected to be low.

c. Prototype installations (Figures B-3 and B-4). A rock overlay was used to rehabilitate a damaged riprap revetment along a railroad embankment on Lake Oahe, near Mobridge, SD. The existing riprap revetment had been damaged by 5-ft waves along 2,700 ft of the 4,500-ft-long embankment. A zero-damage wave height of 5 ft was adopted for design. The rock overlay was sized so that W_{50} was 300 lb (16 in.), and the gradation limits were 150 to 600 lb (13 to 20 in.). A layer thickness of 16 to 18 in. was selected for above-water placement. This was increased to 30 in. for underwater portions of the section. The overlay covered the entire 4,500 ft of existing revetment. Overlay construction was completed in 1971 and was reported to be stable through 1976.

B-3. Field Stone

a. General. A field stone revetment can be constructed using a single layer of heavy subrounded to rounded boulders as the armor layer. Special placement is needed to obtain a close-fitting section. The rounded shapes would normally be considered inadequate for multilayered structures, but satisfactory performance is possible when care is used in placement.

b. Design factors.

(1) Zero-damage wave height is a function of stone weight.

(2) Wave runup potential is estimated to be as low as 50 percent of smooth slope runup.

(3) Wave reflection is expected to be low.

c. Prototype installation (Figures B-5 and B-6). A 5,900-ft-long revetment was built in May 1980 at Kekaha, Kauai, HI, with a southern exposure on the open Pacific coast. The crest elevation is +12 ft MLLW, and the slope is 1 on 1.5. Armor stone weights range from 1.5 to

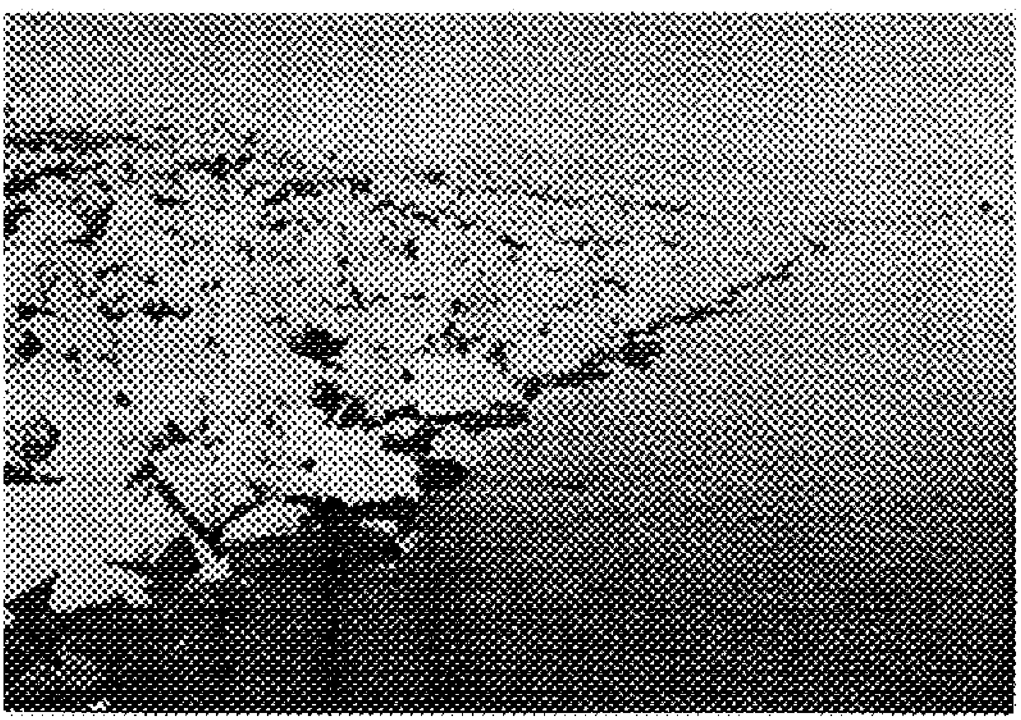


Figure B-3. Large stone overlay revetment at Oahe Reservoir, SD

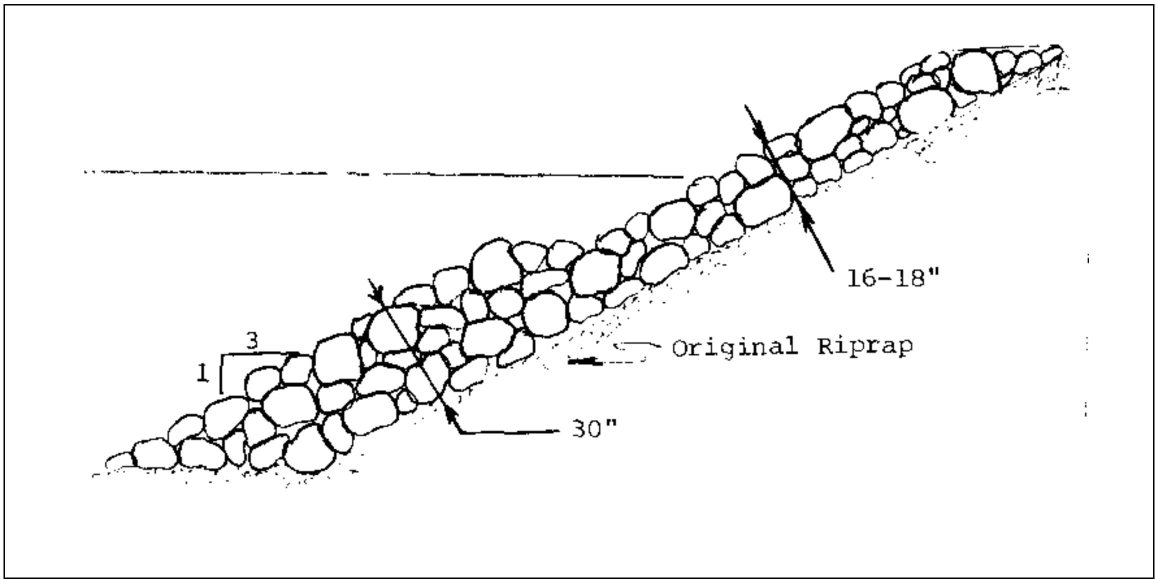


Figure B-4. Large stone overlay revetment cross section

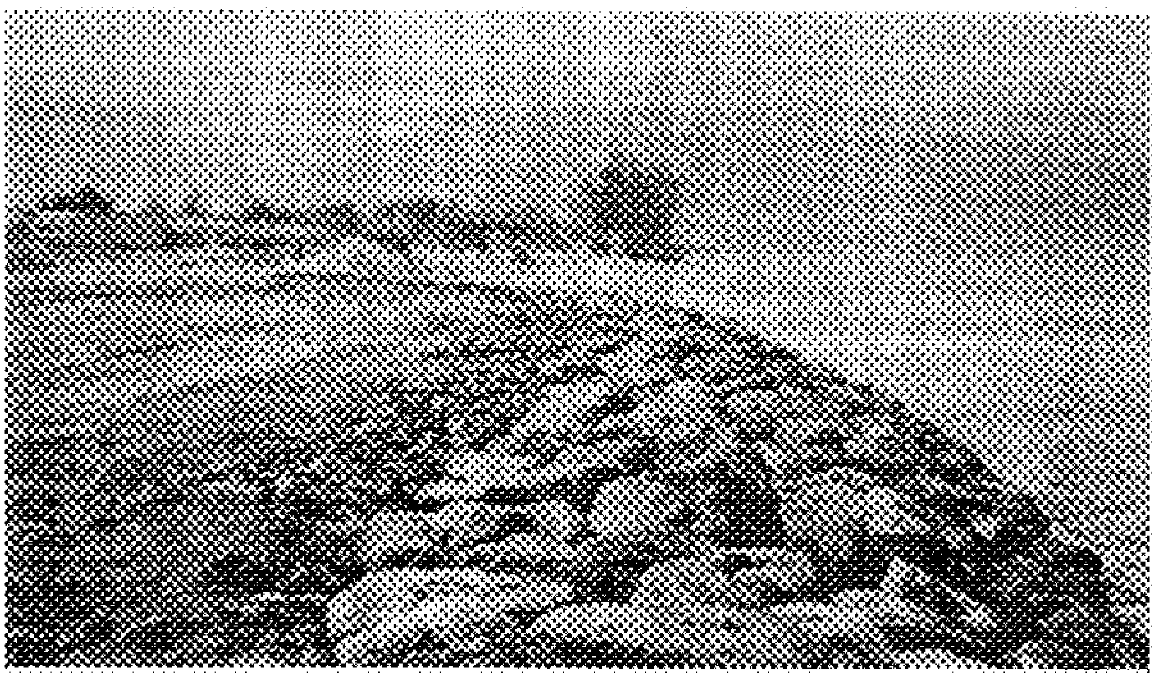


Figure B-5. Field stone revetment at Kekaha Beach, Kauai, HI

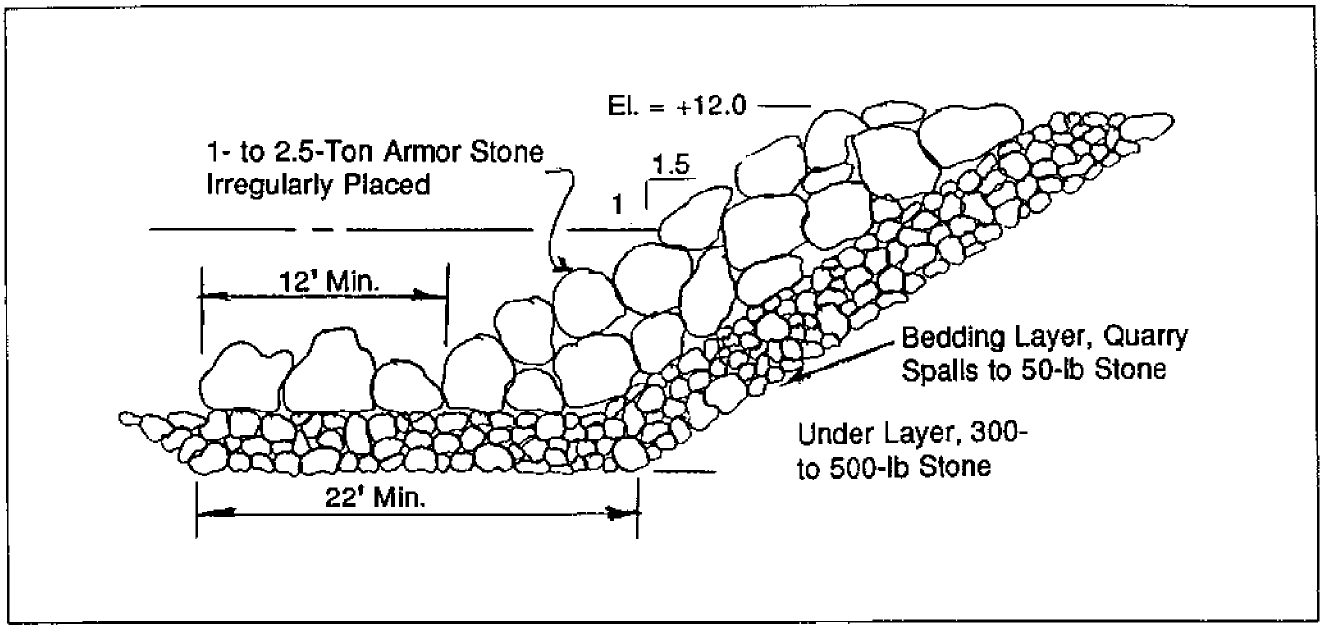


Figure B-6. Field stone revetment cross section

2.5 tons, with underlayer stone from 300 to 500 lb, and a bedding layer that ranges from quarry spalls to 50-lb stone. Mean tide range at the site is 1.6 ft.

B-4. Broken Concrete Rubble

a. General. A concrete rubble revetment utilizes a waste product that otherwise is usually a nuisance. The concrete used in such structures should have the durability to resist abrasion by waterborne debris and attack by salt water and freeze-thaw cycles. In addition, all protruding reinforcing bars should be burned off prior to placement. Failures of concrete revetments have frequently occurred in the past, mostly because of neglect of drainage and filtering requirements. Revetments that have failed at many locations have often consisted of a single layer of rubble dumped on a slope. An improved procedure would be a thicker layer of rubble, with each piece shaped so that the longest dimension is no greater than three times the shortest, thus increasing the revetment stability and minimizing uplift from wave forces. The rubble would be laid directly on the filter layer. An alternative method would utilize shaped-rubble, stacked on a slope, to create a stepped face.

b. Design factors (estimated).

(1) Zero-damage wave height is less than 3 ft.

(2) Wave runup potential for random placement is to be as low as 50 percent of smooth slope runup.

(3) Wave reflection potential for random placement is estimated to be as low as 50 percent.

c. Prototype installations (Figures B-7 and B-8). The final report on the Shore Erosion Control Demonstration Program (Section 54) contains an example of a concrete rubble revetment at Shoreacres, TX, on the northwest shore of upper Galveston Bay, about 15 miles southeast of Houston. The fetch length at the site is about 3 miles, and waves are seldom greater than 3 ft high. Constructed in 1976, it weathered several major storms without significant damage through the end of 1980. No filter material was used, but the rubble was broken into a wide gradation. The structure thickness permitted the natural formation of a filter through sorting processes. This would be expected to occur only for thick revetments containing well-graded rubble. For poorly graded, thinner structures, a properly designed filter layer must be provided. Other examples of concrete rubble revetments occur throughout the United States.

B-5. Asphalt

a. General. Asphalt has been used for revetment construction in a number of ways: as standard asphaltic

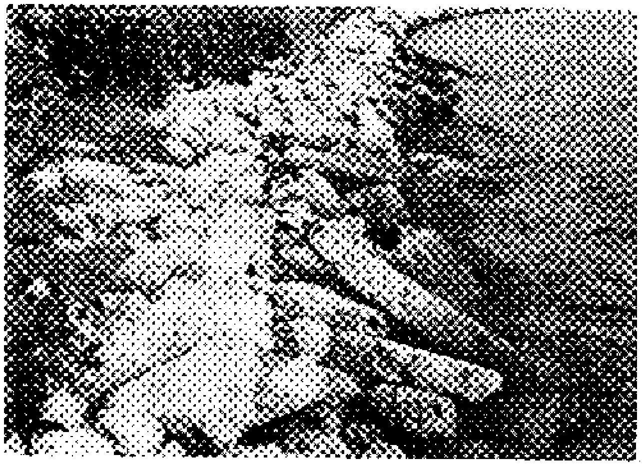


Figure B-7. Broken concrete revetment at Shore Acres, TX

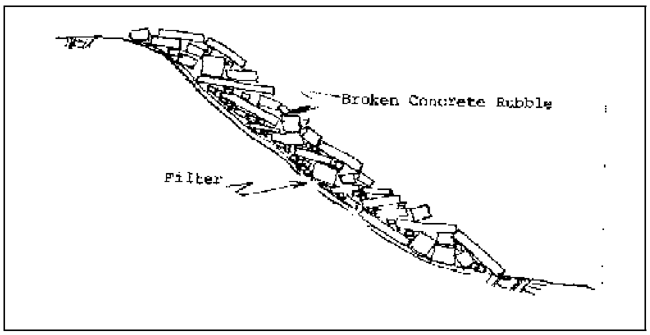


Figure B-8. Broken concrete revetment cross section

concrete paving, as asphalt mastic to bind large stones, and as patch asphalt to join small groups of stone (5 to 10) when it is poured on a slope.

b. Asphaltic concrete paving. Asphaltic concrete paving consists of a standard paving that is placed on a slope as armoring. Stability is an unknown function of the layer thickness. The paving is somewhat flexible which does enhance its stability, but proper filtering and hydrostatic pressure relief are essential due to the impermeable nature of asphalt paving. In addition, asphalt placement underwater is difficult and expensive, and quality control is difficult.

c. Asphalt mastic. In an asphalt mastic revetment, a layer of riprap or quarrystone is bound by pouring hot asphalt over it. This results in a rock-asphalt matrix with superior stability compared to plain rock used alone. Underwater construction is a problem since the mastic cools too quickly to effectively penetrate and bind the rocks together. The extent of this problem is a function of the water depth.

d. Patch asphalt. Patches of asphalt can be poured on a rock slope to bind 5 to 10 rocks together. Model tests revealed an increase in the stability coefficient of two or three times over a nonpatch asphalt slope (McCartney and Ahrens 1976). This procedure has potential either for repairing damaged revetment sections or for original construction. A layer thickness equal to three nominal stone diameters is recommended with the patch generally penetrating only the top two-thirds. The bottom one-third then serves as a reserve should the patch be washed out (d'Angremond et al. 1970).

e. Design factors.

(1) Zero-damage wave height is estimated to be for:

Paving: Function of layer thickness

Mastic: 2 to 4 ft

Patch: Function of rock size

(2) Wave runup potential is estimated to be for:

Paving: 100 percent of smooth slope runup

Mastic: 80-100 percent of smooth slope runup as function of the thickness of mastic

Patch: 60-70 percent of smooth slope runup

(3) Wave reflection potential is estimated for:

Paving and Mastic: High

Patch: Medium

f. Prototype installations. Asphalt paving was used at the Glen Anne Dam in California. This consisted of a 1-ft-thick layer of slope protection on the 1 on 4 upstream dam face. A similar treatment was tested at Bonny Dam in Colorado (Figure B-9) (McCartney 1976). At another site at Point Lookout, MD, an asphalt concrete revetment protects both sides of a 2,200-ft-long causeway that extends into Chesapeake Bay. The revetment, placed on a 1 on 4 slope, is 4 in. thick. It was placed in two lifts with welded wire fabric placed between the lifts (Asphalt Institute 1965). Long-term performance data are not available. A rock-asphalt mastic revetment was

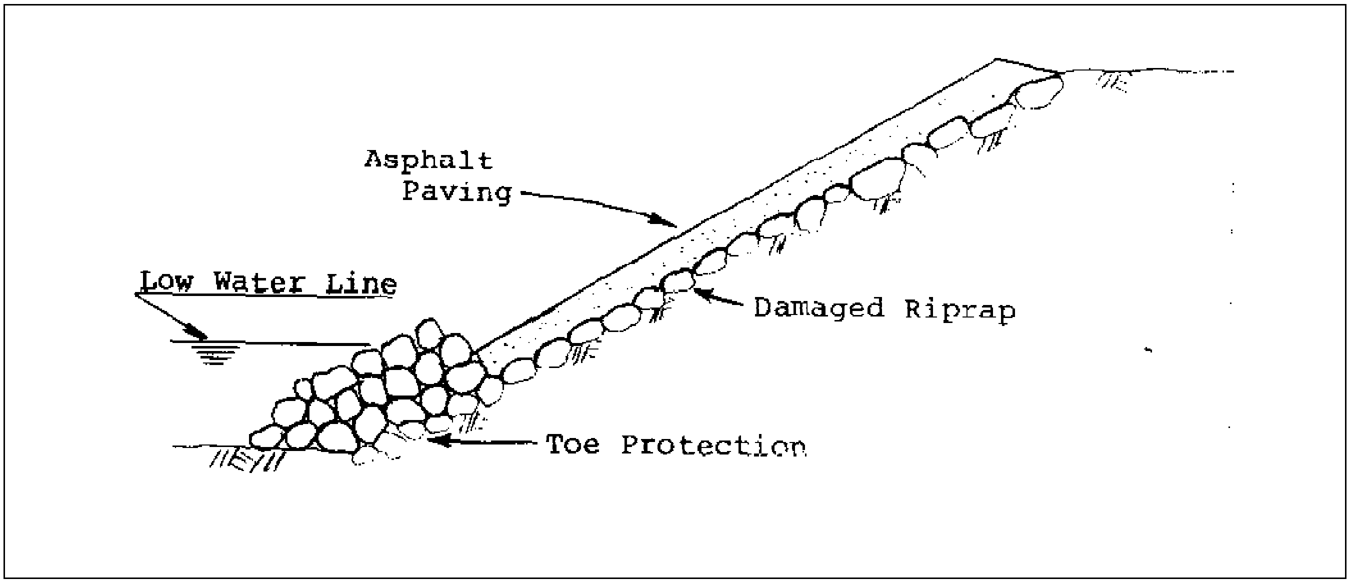


Figure B-9. Asphaltic concrete revetment cross section

installed at Michiana, MI, on Lake Michigan. It consisted of a thin layer of small rock (less than 12 in.) covered with asphalt to form a mat. This revetment performed well for a short time then deteriorated (Brater et al. 1974). No prototype installations of patch asphalt revetments have been reported.

B-6. Concrete Armor Units

a. General. Concrete armor units such as tribars, tetrapods, and dolosse can be used in place of stone for rubble structures, including revetments. Size selection is in accordance with the methods outlined in paragraphs 2-15 to 2-18. As described in those paragraphs, some kinds of armor units exhibit stability against wave attack equaling two to six times that of equal weight armor stones. Concrete units, however, are usually not economical where there is a local source of suitable rock.

b. Design factors.

(1) Zero-damage wave height is a function of armor unit size.

(2) Wave runup potential is estimated to be 50 to 80 percent of smooth slope runup.

(3) Wave reflection potential is estimated to be low to medium.

c. Prototype installations. Hudson (1974) contains examples of coastal structures utilizing concrete armor units. In addition, model tests of various armor unit shapes have been made by CERC (McCartney 1976) at WES (Figures B-10 and B-11) and other laboratories.

B-7. Formed Concrete

a. General. Revetments of this kind consist of a slab-on-grade cast in place at the site. The face can be smooth or stepped, and the structure may be capped with a curved lip to limit overtopping from wave runup. Toe protection may be either dumped rock or a sheet pile cut-off wall, and provision must be made for relief of hydrostatic pressures behind the wall and for proper filtering. Construction of this kind is usually more expensive than riprap or quarrystone.

b. Design factors.

(1) Zero-damage wave height is a function of concrete thickness.

(2) Wave runup potential is estimated to be 100 percent of smooth slope runup.

(3) Wave reflection potential is estimated to be high.

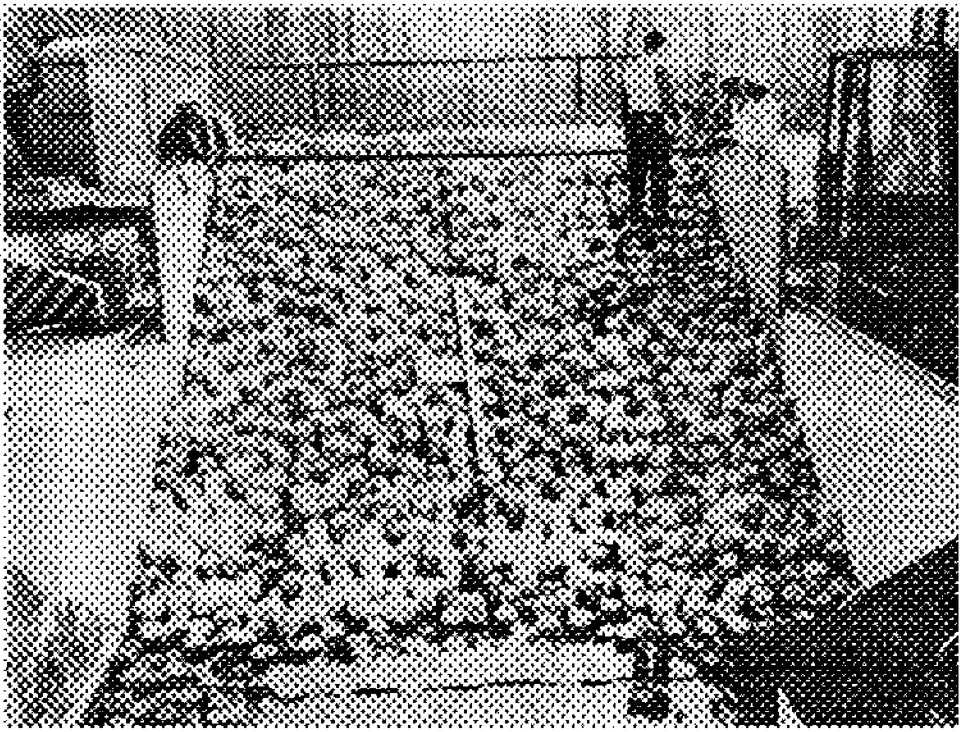


Figure B-10. Concrete tribars (armor unit) test section at CERC, Fort Belvoir, VA

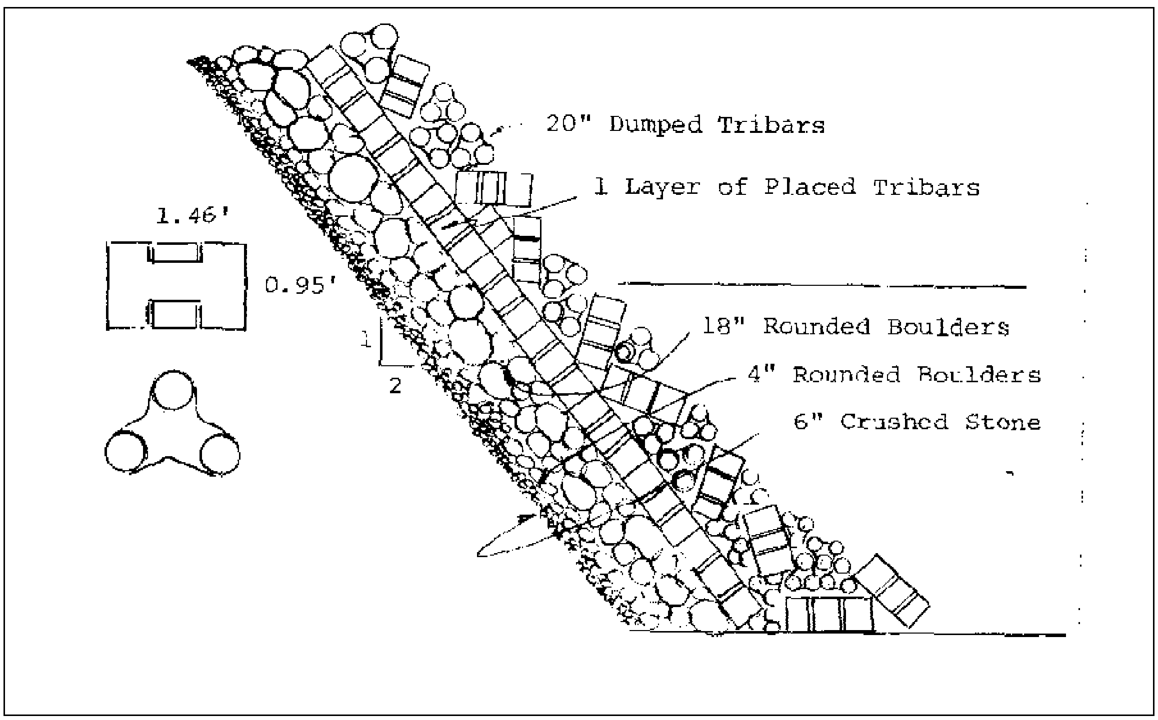


Figure B-11. Concrete tribar revetment cross section *c. Prototype installations.* A revetment of formed concrete was built before 1966 at Cambridge, MD (Figures B-12 and B-13). Subsequent performance data are unavailable, but such revetments should be relatively maintenance-free for many years provided there is control over toe scour and flanking. Revetments similar to the one shown have been built throughout the United States.

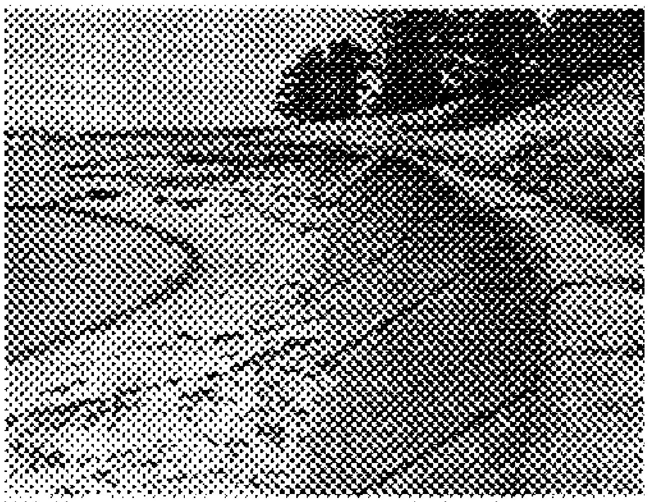


Figure B-12. Formed concrete revetment, Pioneer Point, MD

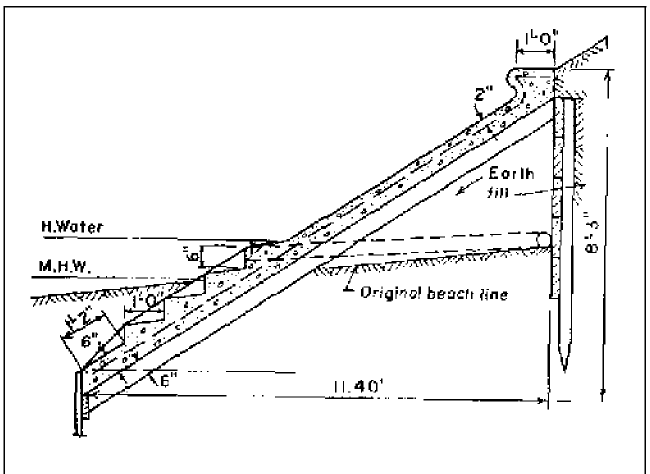


Figure B-13. Formed concrete revetment cross section

B-8. Concrete Blocks (Figure B-14)

Prefabricated concrete blocks are commonly used as a substitute for quarrystone or riprap. Many designs are available, and new shapes are being offered on a regular basis to replace those that have not been accepted by the marketplace. Designers must be prepared to invest time to stay abreast of current developments in this field. Revetment blocks are usually designed with various intermeshing or interlocking features, and many of the units are patented. Blocks have the advantage of a neat, uniform appearance, and many units are light enough to be installed by hand once the slope has been prepared. The disadvantage of concrete blocks is that the interlocking feature between units must be maintained. Once one block is lost, other units soon dislodge and complete failure may result. A stable foundation is required since settlement of the toe or subgrade can cause displacement of the units and ultimate failure. Also, most concrete block revetments have relatively smooth faces that can lead to significantly higher wave runup and overtopping than those with dumped rock.

B-9. Gobi (Erco) and Jumbo Blocks and Mats

a. General. Gobi blocks are patented units that weigh about 13 lb each. Erco blocks are similar, but they are offered by a different licensed manufacturer. Jumbo blocks are large-sized Erco blocks that weigh about 105 lb each. The units are designed for hand placement on a filter cloth, or they are factory-glued to carrier strips of filter cloth. The latter are called Gobimats (Ercomats) or Jumbo Ercomats, depending on the size of the units. If the blocks are glued to both sides of the carrier strip, back-to-back, they are called double Gobimats (Ercomats) or double Jumbo Ercomats. The blocks used for producing mats have tapered sides to facilitate bending. Blocks designed for hand placement have vertical sides to provide the tightest possible fit. Mats are preferred at sites where vandalism or theft is possible. Both single and double mats require machine placement. Back filling of the blocks with sand or gravel increases the stability of the revetment, and any grass that grows through the block openings will further increase the strength.

b. Design factors.

Zero-damage wave height:

Blocks: 2 ft (McCartney 1976)
Mats: 4 ft (estimated)

Wave runup potential: 90 percent of smooth slope runup (Stoa 1979)

Wave reflection potential: High (estimated)

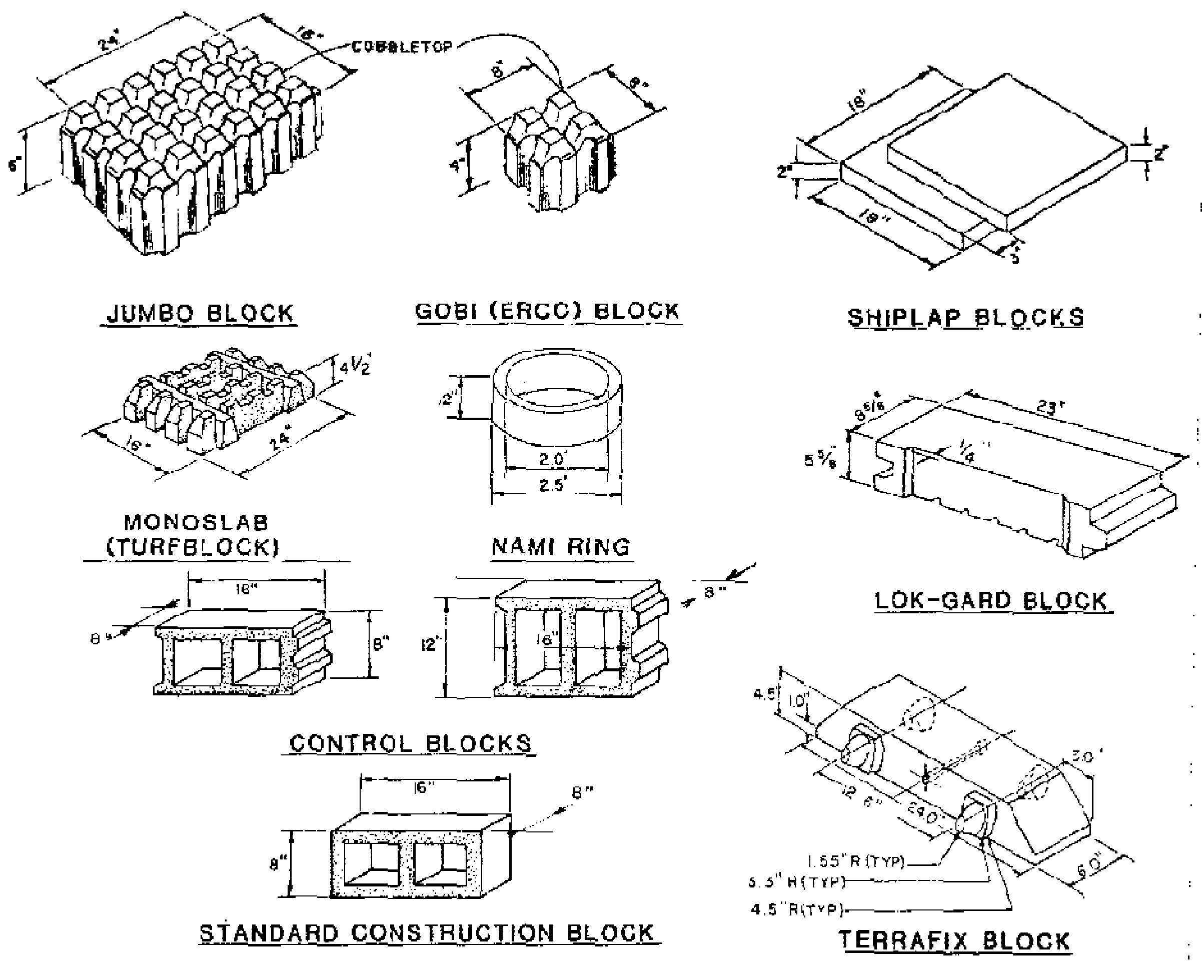


Figure B-14. Concrete revetment blocks

c. Prototype installations (Figures B-15 and B-16). According to the final report on the Shoreline Erosion Control Demonstration Program (Section 54) the largest Gobi block revetment in the United States is probably the one located at Holly Beach, LA, which occupies about 4 miles of shore front. Installed in 1970 and repaired and extended in 1976, the revetment suffered only relatively minor damages prior to Tropical Storm Claudette in July 1979, which displaced or otherwise damaged about one-half of the revetment. Waves during that storm probably exceeded the design condition, and the blocks, individually placed, were susceptible to unravelling after the initial blocks were lost. Use of mats with the blocks glued to the carrier strips would be preferable for areas where waves greater than 3 ft are likely.

B-10. Turfblocks or Monoslabs

a. General. Turfblocks are patented units that are designed for hand placement on a filter with the long axes parallel to the shoreline. Each block measures 16 × 24 × 4.5 in. and weighs approximately 100 lb. Field installations have not yielded conclusive results, but their performance should be similar to that of Jumbo Erco blocks. Their thin, flat shape requires a stable foundation,

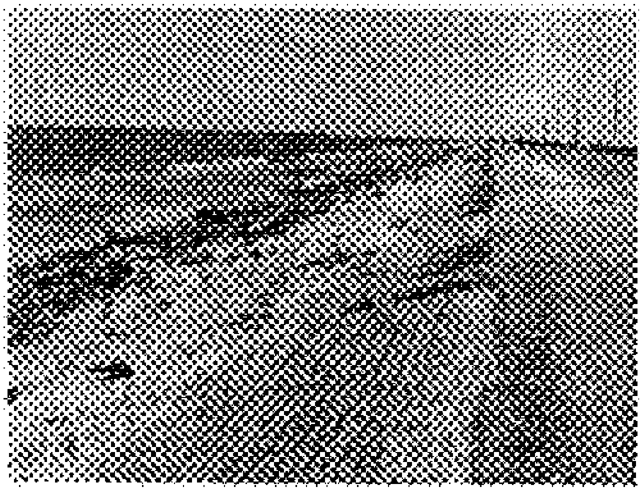


Figure 15. Gobi block revetment, Holly Beach, LA

as any differential settlement beneath the blocks makes them susceptible to overturning under wave action.

b. Design factors (estimated).

(1) Zero-damage wave height is 2 ft.

(2) Wave runup potential is 90 percent of smooth slope runup.

(3) Wave reflection potential is high.

c. Prototype installation (Figures B-17 and B-18). Well-documented in the final report on the Shoreline Erosion Control Demonstration Program (Section 54) is an example of a Turfblock revetment at Port Wing, WI, on Lake Superior. Completed early in November 1978, it immediately experienced greater than design wave conditions. Large waves overtopped the structure, and considerable displacement and settling of the blocks occurred. Breaking wave heights during the storm were estimated to be greater than 6 ft. The most likely cause of failure was uncompacted fill material that contained large boulders. Consolidation of this material after construction was completed may have subjected the blocks to differential settlement. Blocks left resting on boulders became tilted and vulnerable to overturning. Failure may have begun with a few isolated blocks and then quickly spread throughout the revetment. The blocks seem to be sufficiently heavy because they were not displaced very far from their initial positions.

B-11. Nami Rings

a. General. The Nami Ring is a patented concrete block shaped like a short section of pipe, 2.5 ft in diameter by 1 ft in height, which weighs 240 lb. The rings are placed side-by-side on a slope over a filter. Better

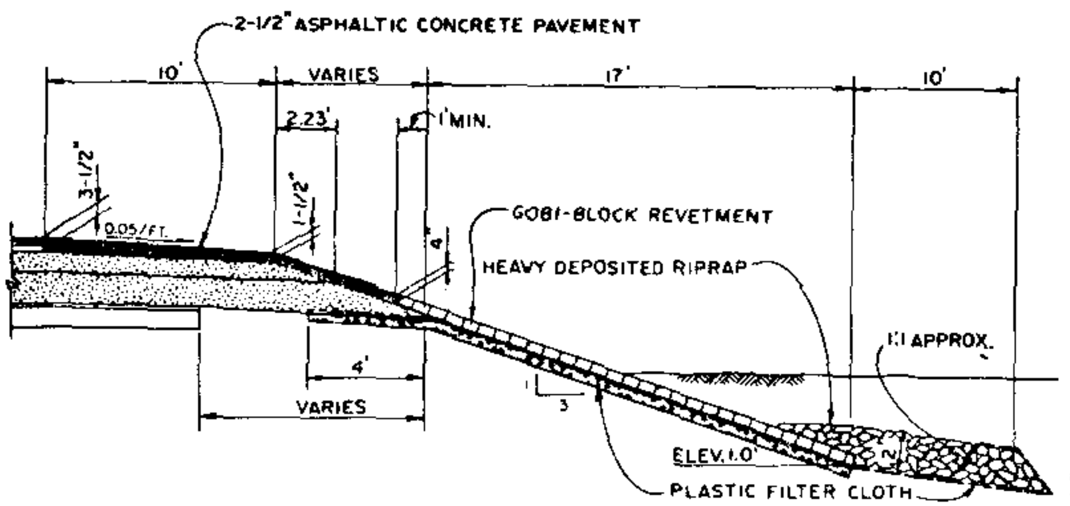


Figure B-16. Gobi block revetment cross section

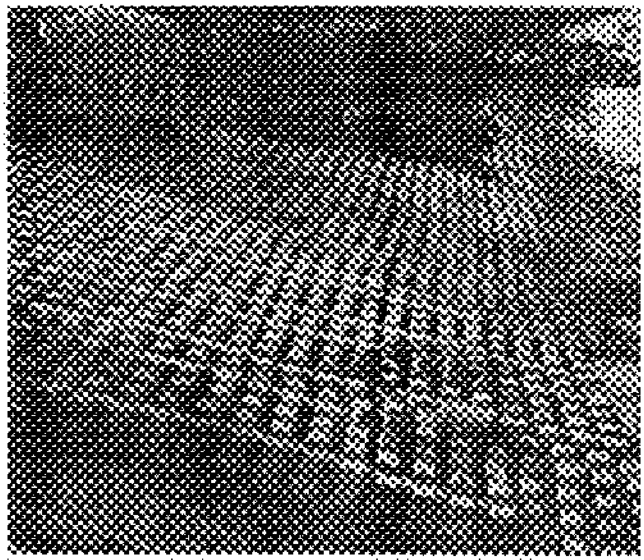


Figure B-17. Turfblock revetment, Port Wing, WI

performance has been observed when the rings are joined together with tie rods. Sand or gravel caught in the wave turbulence tends to be deposited inside the rings and in the voids between adjacent rings, adding to the stability of the section and protecting the filter cloth. Because of their shape, Nami Rings are susceptible to severe abrasion and damage by waterborne cobbles and, therefore, should be used primarily in sandy environments.

b. Design factors (estimated).

(1) Zero-damage wave height is 3 ft.

(2) Wave runup potential is 50 to 90 percent of smooth slope runup.

(3) Wave reflection potential is medium to high.

c. Prototype installation (Figures B-19 and B-20). A fairly well-documented site (final report on the Shoreline Erosion Control Demonstration Program) is at Little Girls Point, MI. on Lake Superior. A 300-ft Nami Ring revetment was placed there in 1974. The revetment was intended as toe protection for an eroding bluff and was to be installed on a 1V on 1.5H graded slope along the beach at the bluff's base. Regrading was never done, and the revetment was installed on the existing beach without excavating the toe to LWD. The number of blocks was insufficient. The revetment was too low to prevent significant overtopping. The rings were susceptible to waterborne debris. Many were shattered by high waves. Their ability to trap sand is impressive and this protective mantle tends to shield the rings from damage. The filled rings offer a considerably smooth surface, however, so that runup increases with age. Field surveys in 1979 showed that the revetment was almost entirely filled with littoral material and was no longer functioning as originally intended. Better performance would have occurred with a properly graded slope, toe protection, and better

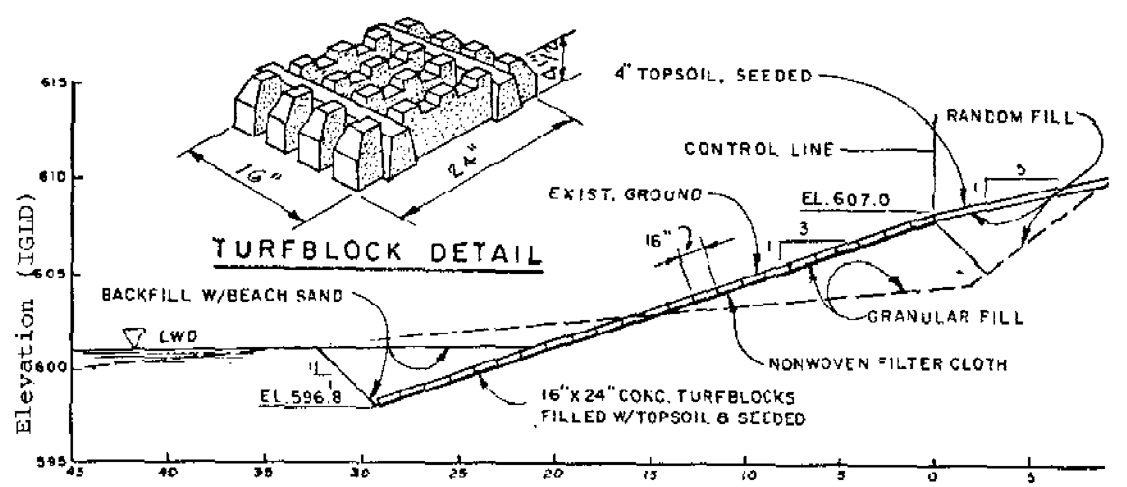


Figure B-18. Turfblock revetment cross section

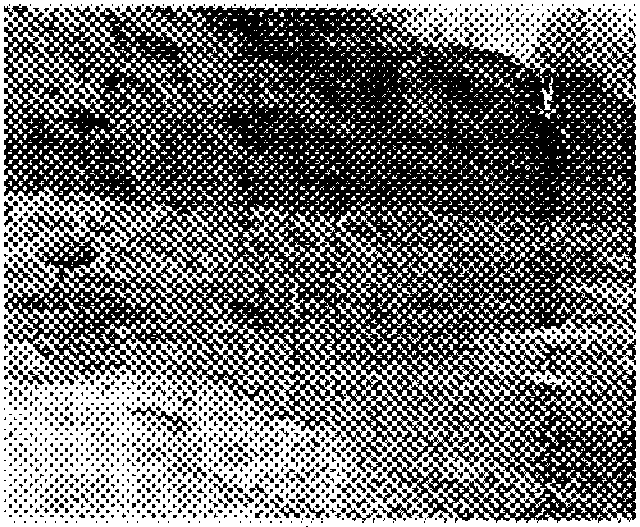


Figure B-19. Nami Ring revetment, Little Girls Point, MI

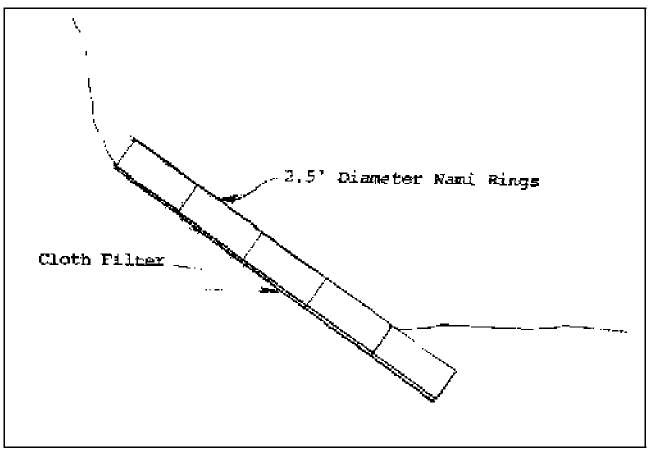


Figure B-20. Nami Ring revetment cross section

filtering. Improved filtering is especially important because the initial failure occurred in the half of the revetment that had no filter and then spread to the other half that was underlain with filter cloth.

B-12. Concrete construction blocks

a. General. Standard concrete construction blocks can be hand placed on a filter cloth with their long axes perpendicular to the shoreline and the hollows vertical. Their general availability is a primary advantage, but they are highly susceptible to theft. They form a deep, tightly fitting section which is stable provided the toe and flanks are adequately protected. The failure has been the most prominent problem with concrete construction block revetments tested at prototype scale (Giles 1978). Another disadvantage is that standard concrete for building construction is not sufficiently durable to provide more than a few years service in a marine environment. Special concrete mixes should be used when possible.

b. Design factors (estimated).

(1) Zero-damage wave height is 4 ft.

(2) Wave runup potential is 80 to 90 percent of smooth slope runup.

(3) Wave reflection potential is high.

c. Prototype installations (Figures B-21 and B-22). Concrete block revetments have been built throughout the United States (Shoreline Erosion Control Demonstration Program Report). Monitoring data are available for one built along the north shore of Lake Pontchartrain in Louisiana. Constructed in November 1979, it utilized standard 8- by 16-in. blocks placed hollows-up on a woven filter cloth. In January 1980, a section of blocks was stolen from the revetment, a reason for caution when using common materials such as these. In April 1980, a storm dislodged several blocks, and the toe settled unevenly into the lake bottom. During repair efforts, the blocks were inadvertently placed with their long axes parallel to shore; consequently, they were readily displaced again by large waves. This displacement suggests that greater stability may be available when blocks are placed with their long axes perpendicular to shore. Overall, the structure performed adequately in the sheltered, mild wave climate area of this site.

B-13. Concrete Control Blocks

a. General. Concrete control blocks come in various sizes and are similar to standard concrete construction blocks except that protrusions in the block ends provide a tongue-and-groove interlock between units. Designed to be hand placed on a filter cloth with the cells vertical, the blocks can be aligned with their long axes parallel to shore, but optimum performance probably results from placement perpendicular to the water's edge.

b. Design factors (estimated).

(1) Zero-damage wave height is 5 ft.

(2) Wave runup potential is 50 to 90 percent of smooth slope runup.

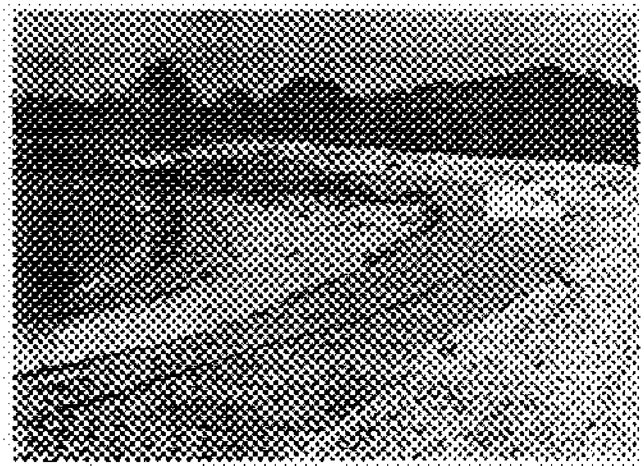


Figure B-21. Concrete construction block revetment, Fontainebleau, State Park, LA

(3) Wave reflection potential is medium to high.

c. Prototype installation (Figures B-23, B-24, and B-25). Two small revetments using control blocks were constructed at Port Wing, WI, on Lake Superior in October 1978 (Shoreline Erosion Control Demonstration Program Report). One revetment used 10-in. by 16-in. blocks (8 in. deep), and the other used smaller 8-in. by 16-in. blocks (also 8 in. deep). In both cases the long axes were placed parallel to the waterline and utilized a simple buried toe. The devices performed well through 1982 and withstood several episodes of large waves, including the one in November 1978 that destroyed the neighboring Turfblock revetment (paragraph B-10). Simple burial of the toe appears to be an inadequate treatment at this site, and progressive unravelling of the revetment from the toe was evident by 1982. Also, the concrete used in manufacturing the blocks appears inadequate to withstand abrasion and freeze-thaw cycles at the site. The blocks near the waterline were clearly showing signs of deterioration by 1979 as shown in Figure B-23.

B-14. Shiplap Blocks

a. General. Shiplap blocks are formed by joining standard or other size patio blocks with an epoxy adhesive. The resulting weight of the units depends on the size of the basic blocks used. Table B-1 lists the weights for several block sizes.

b. Design factors.

(1) Zero-damage wave heights.

Small blocks: 4 ft (Hall and Jachowski 1964).

Large blocks: 5 ft (estimated).

(2) Wave runup potential is estimated to be 90 to 100 percent of smooth slope runup.

(3) Wave reflection potential is estimated to be high.

c. Prototype installations.

(1) Small blocks (Figures B-26 and B-27). The first widely known shiplap block revetment was the one built on the east bank of the Patuxent River opposite Benedict, MD. Described in Hall and Jachowski (1964), it

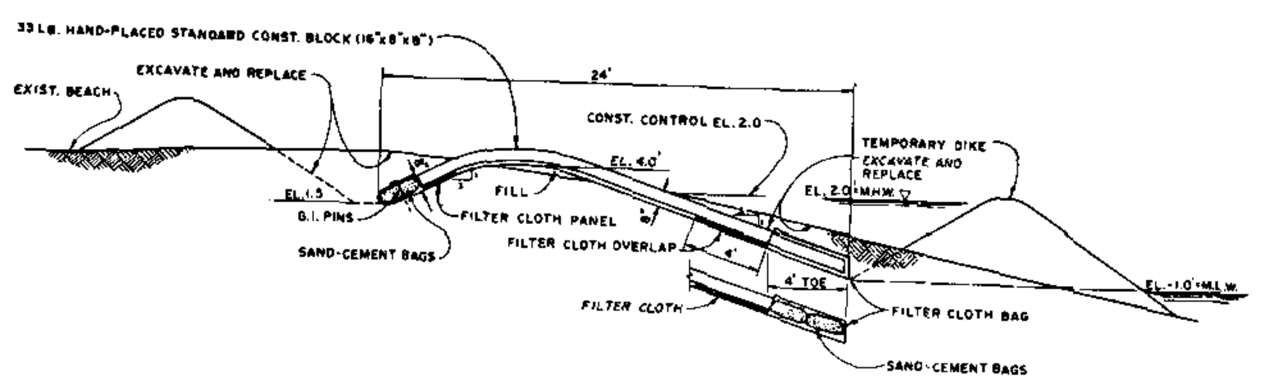


Figure B-22. Concrete construction block revetment cross section

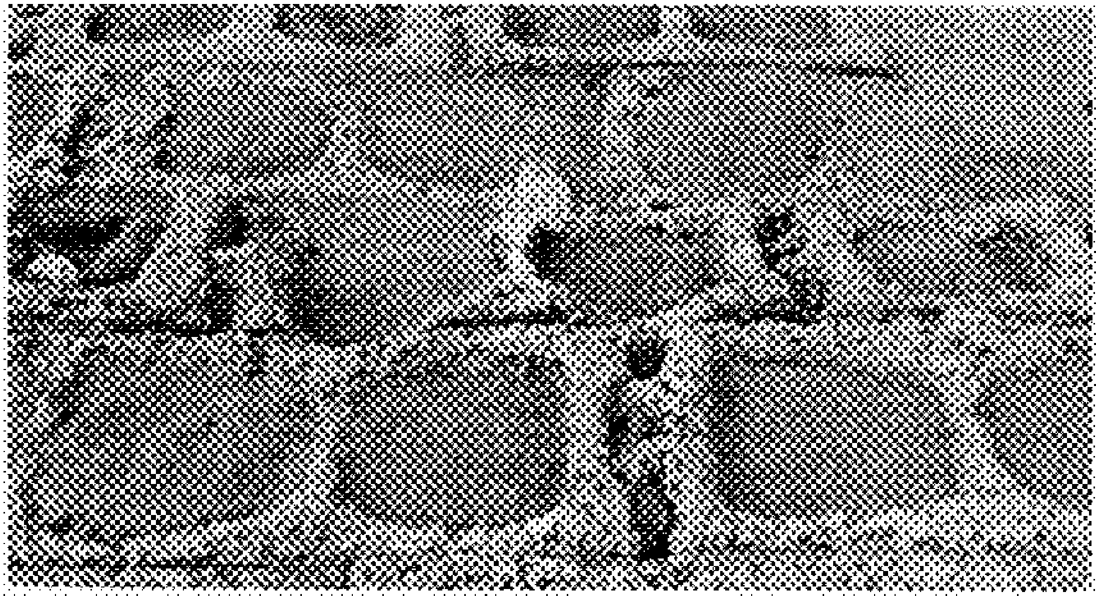


Figure B-23. Detail of erosion of concrete control blocks

Figure B-24. Concrete control block revetment, Port Wing, WI

consisted of units of two 8- by 16- by 2-in. blocks glued together at a 3-in. offset in two directions. The structure was completed in July 1962, and provided long service. A similar revetment was constructed in 1964 near the mouth of the Choptank River in the vicinity of Oxford, MD (Hall 1967). Model tests at prototype scale, using similar 18- by 18- by 3-in. blocks revealed the need for spacers or slots to relieve excess hydrostatic pressures behind the blocks.

(2) Large blocks. A large revetment was constructed at Jupiter Island, FL, with alternating 3-ft square, 10- and 14-in. thick blocks (Wilder and Koller 1971). This revetment was later damaged during a storm with failure occurring either due to a weakness at the toe or through inadequate filtering or hydrostatic pressure relief.

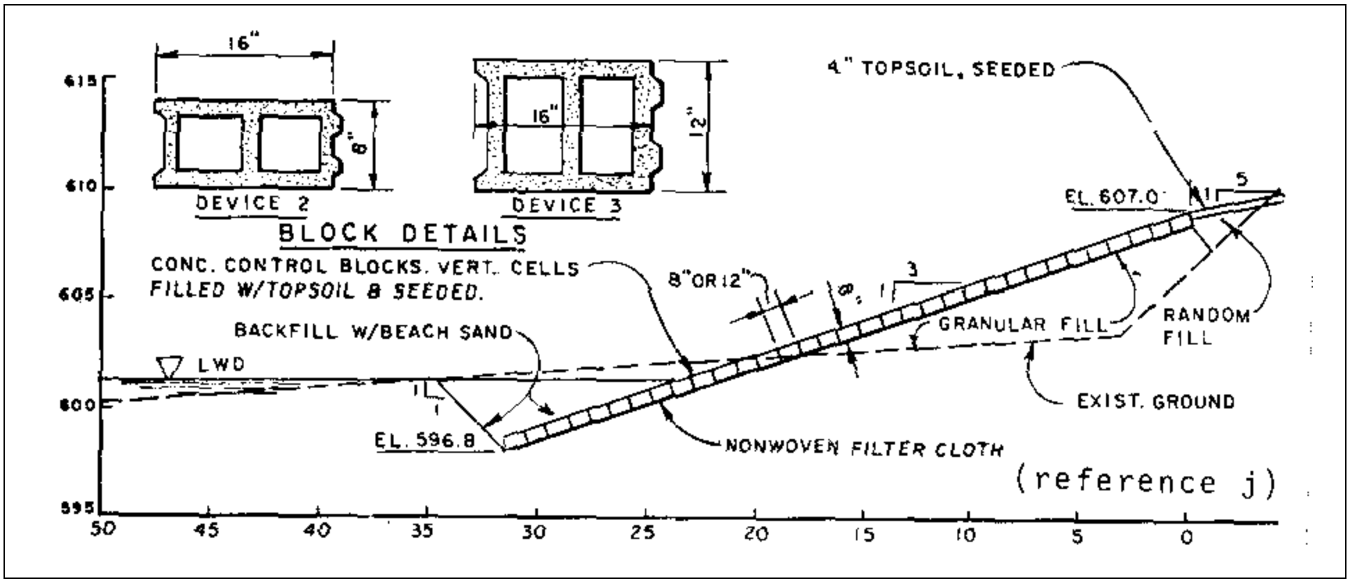


Figure B-25. Concrete control block revetment cross section

Table B-1
Shiplap Block Weights

Two-Block Glued Unit in.	Weight lb
8 x 16 x 4	40
18 x 18 x 6	160
36 x 36 x 20	2,100
36 x 36 x 28	2,940

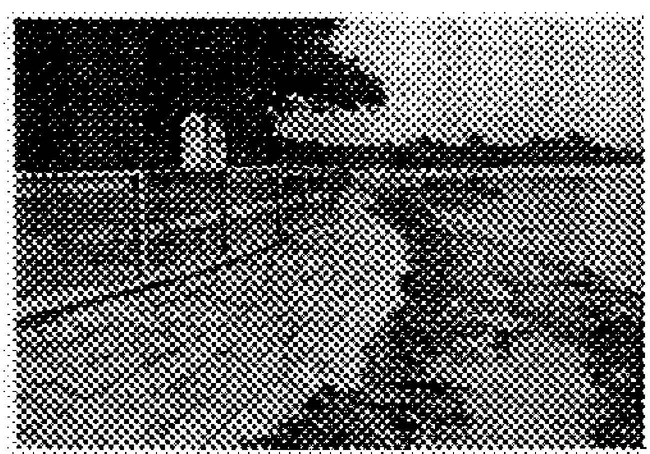


Figure B-26. Shiplap block revetment, Benedict, MD

B-15. Lok-Gard Blocks

a. General. Lok-Gard blocks are joined with a tongue-and-groove system. The patented 80-lb units are designed for hand placement with their long axes perpendicular to shore. The finished revetment has a smooth surface which results in high runup and overtopping potential.

b. Design factors (estimated).

Zero-damage wave height is 4 ft.

Wave runup potential is 100 percent of smooth slope runup.

Wave reflection potential is high.

c. Prototype installations. A Lok-Gard revetment was constructed on Tilghman Island at Cedarhust, MD, in the 1960's (Mohl and Brown 1967). Eight hundred feet of shoreline were protected with blocks placed on a 1V:2H slope. The estimated storm wave height at the site was 5 ft which is approximately at the upper stability range for these blocks (Hall 1967). Relief of hydrostatic pressure is critical, so only blocks with pressure relief slots along one side should be used. A similar revetment was constructed along the Jensen Beach Causeway in

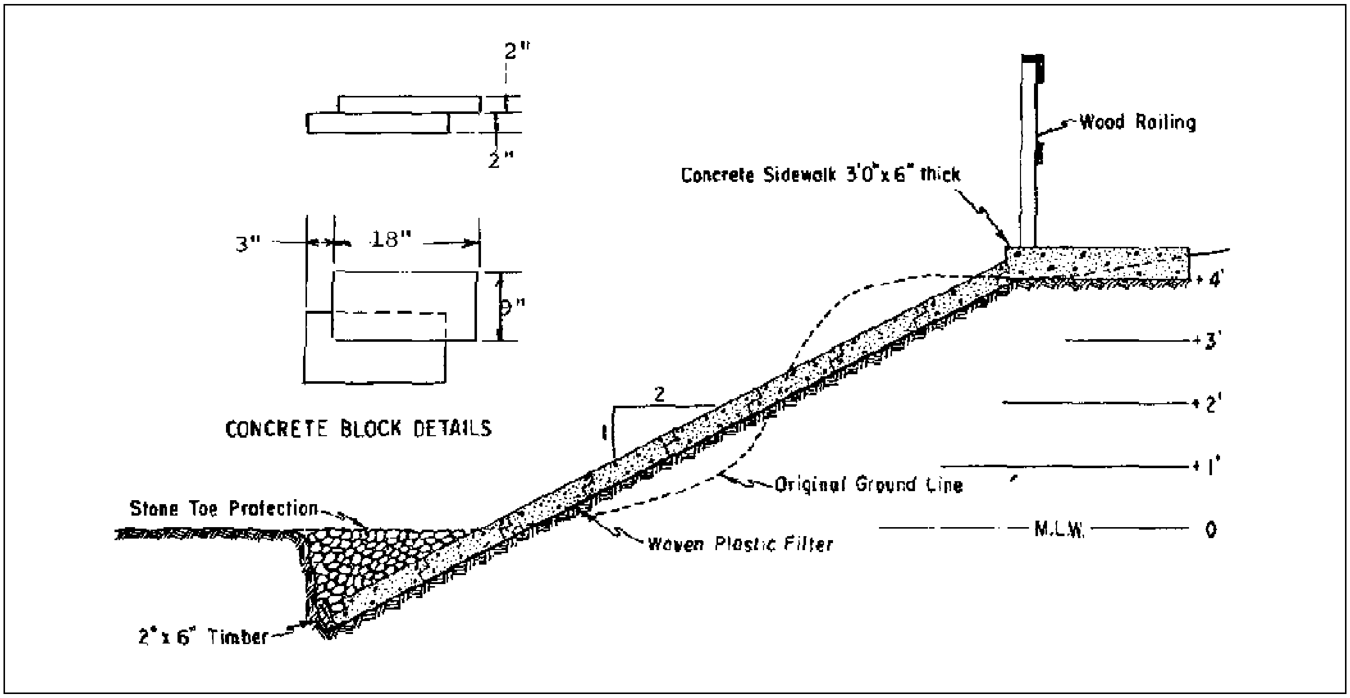


Figure B-27. Shiplap block revetment cross section

Florida in 1980 (final report on the Shoreline Erosion Control Demonstration Program) (Figures B-28 and B-29). The site is sheltered, and maximum expected waves are on the order of 3 ft high. Performance was satisfactory through 1982.

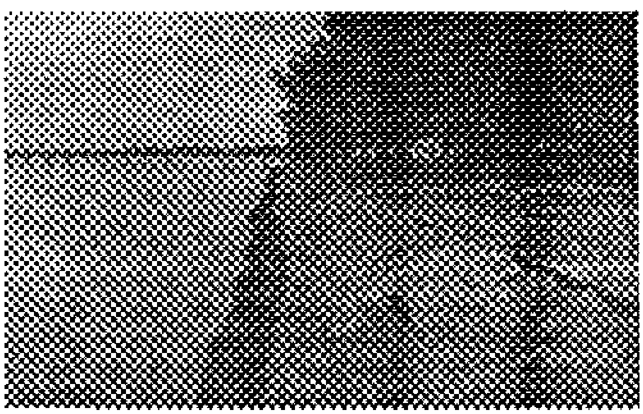


Figure B-28. Lok-Gard block revetment, Jensen Beach Causeway, FL

B-16. Terrafix Blocks

a. General. Terrafix blocks are patented units that are joined with a mortise and tenon system and have cone-shaped projections which fit holes in the bottom of the adjacent blocks. In addition, holes through the center of each block allow for stainless steel wire connection of many individual blocks. The uniform interlocking of the 50-lb units creates a neat, clean appearance.

b. Design factors (estimated).

(1) Zero-damage wave height is 5 ft.

(2) Wave runup potential is 90 percent of smooth slope runup.

(3) Wave reflection potential is high.

c. Prototype installations (Figures B-30 and B-31). Specific details about field installations and locations are unknown. A photograph of a site at Two Mile, FL, and a typical Terrafix revetment section are shown.

B-17. Fabric Containers

Several manufacturers produce bags and mats in various sizes and fabrics that can be used for revetment construction when filled either with sand or a lean concrete mixture. Bags can be placed directly on the slope in a single layer, or they can be stacked in a multiple layer running up the slope. Mattresses are designed to be laid flat on a

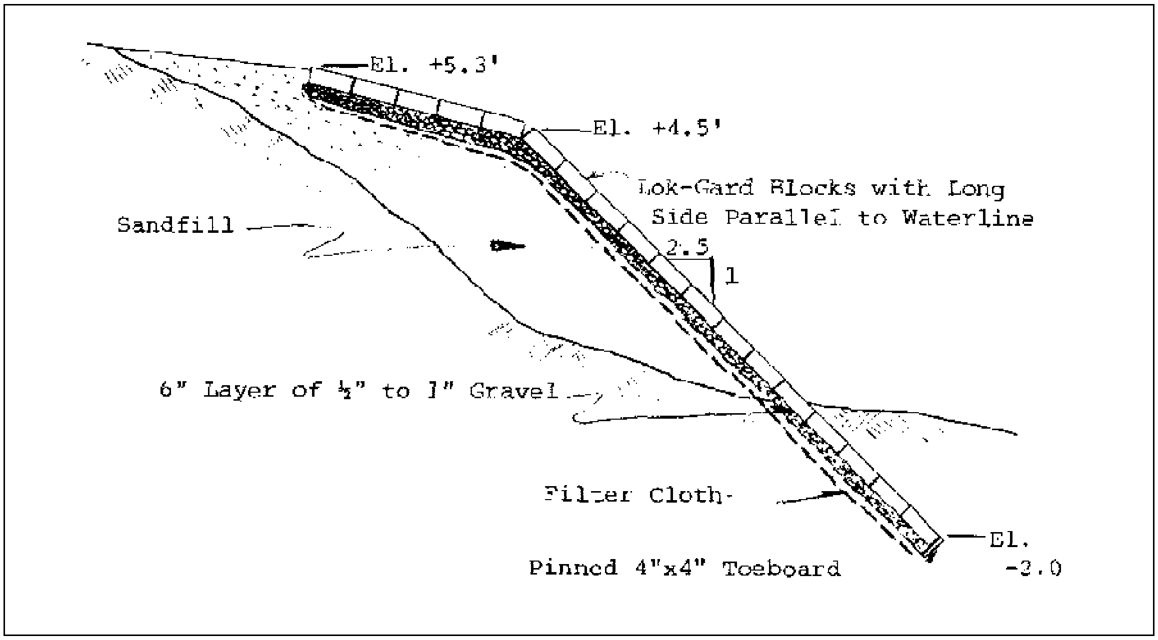


Figure B-29. Lok-Gard block revetment cross section

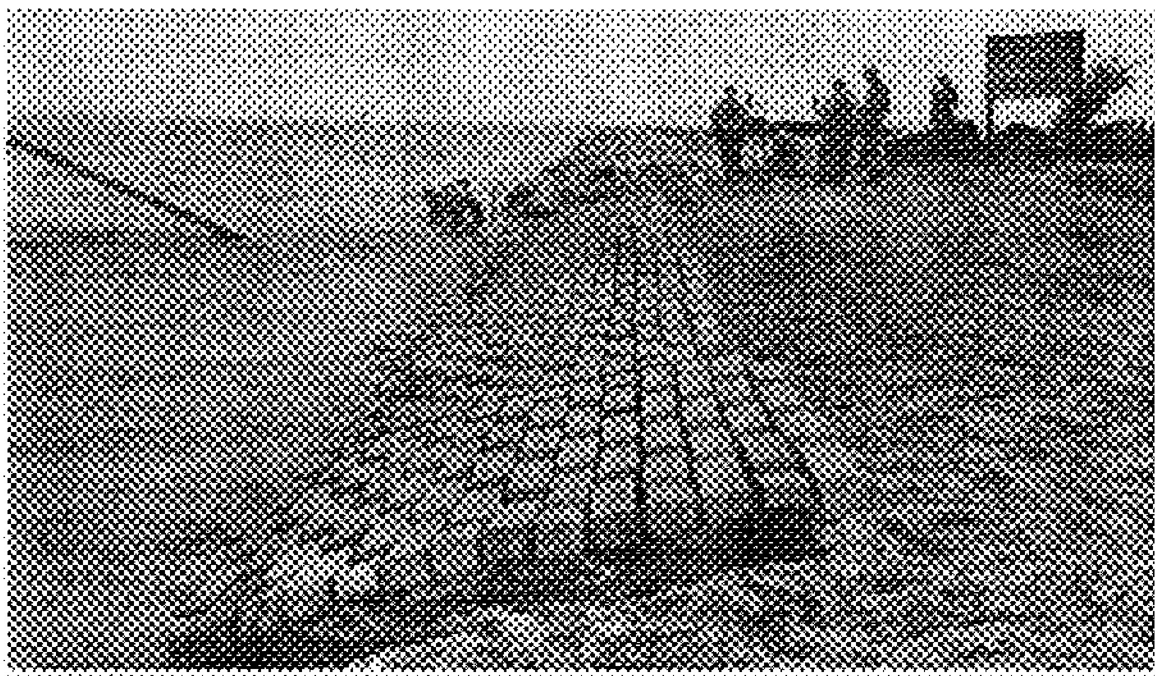


Figure B-30. Terrafix block revetment, Two Mile, FL

slope. The advantages of bag revetments are their ease of construction and moderate initial cost. Sand-filled units are relatively flexible and can be repaired easily. Their disadvantages are susceptibility to vandalism, damage from waterborne debris, and degradation under ultraviolet light. Concrete fill eliminates these problems at a high cost and loss of structural flexibility. Placement should always be on a stable slope. A stacked bag revetment can be placed on a steeper slope than a blanket revetment or

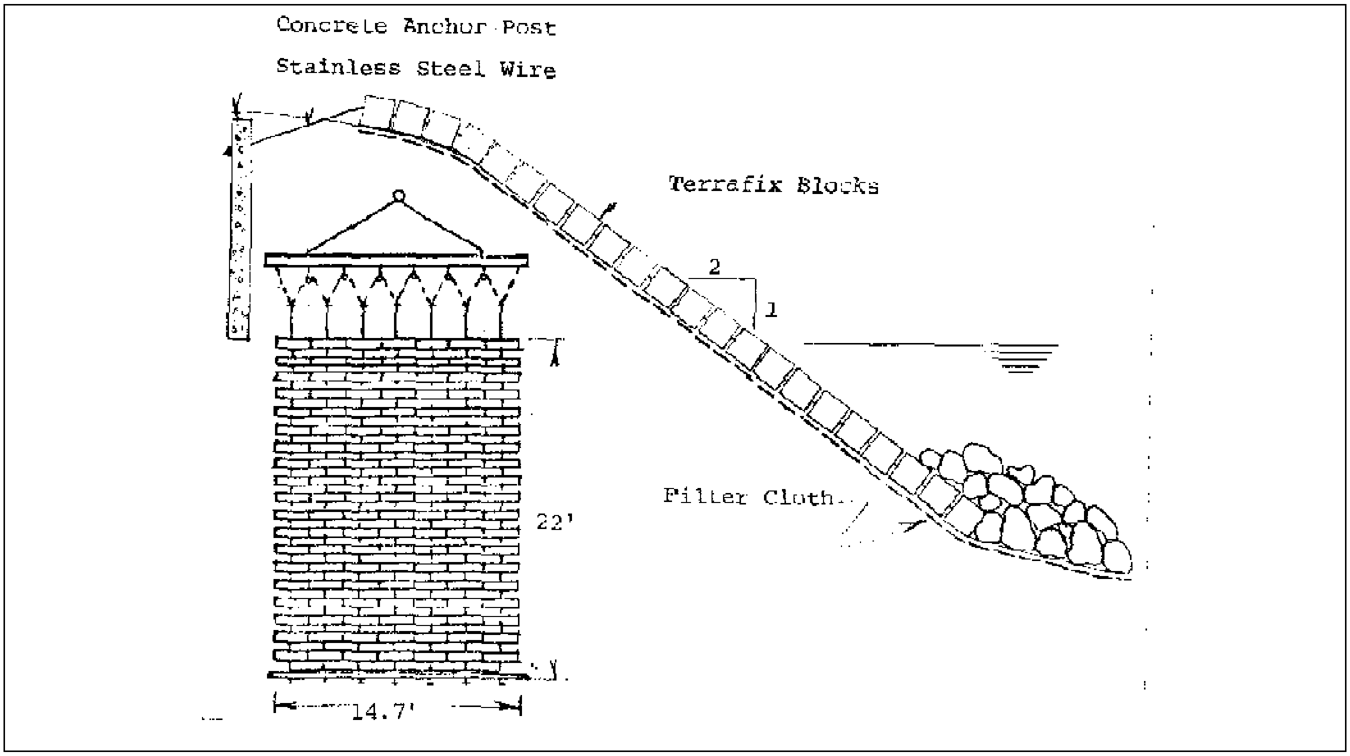


Figure B-31. Terrafix block revetment cross section

mattress, but in no case should the slope exceed IV on 1.5 H.

B-18. Mattresses

a. General. Mattresses are designed for placement directly on a prepared slope. Laid in place when empty, they are joined together and then pumped full of concrete. This results in a mass of pillow-like concrete sections with regularly spaced filter meshes for hydrostatic pressure relief. Installation should always be in accordance with the manufacturer's recommendations.

b. Design factors (estimated).

(1) Zero-damage wave height is 3 ft.

(2) Wave runup potential is 95 to 100 percent of smooth slope runup.

(3) Wave reflection potential is high.

c. Prototype installation (Figures B-32 and B-33). The best example of a concrete mattress subjected to wave action is the upstream face of Allegheny Reservoir (Kinzua Dam) in northern Pennsylvania and southern New York. Built in 1968, the Fabriform nylon mat was placed 53 ft down a 1-on-1.5-slope and, through 1980, was functioning as designed. The panels were anchored in a trench about 7 ft above the high water level. A large portion of the lower part of the revetment was constructed with the nylon fabric forms under water. Because the mattress is essentially a collection of discrete concrete

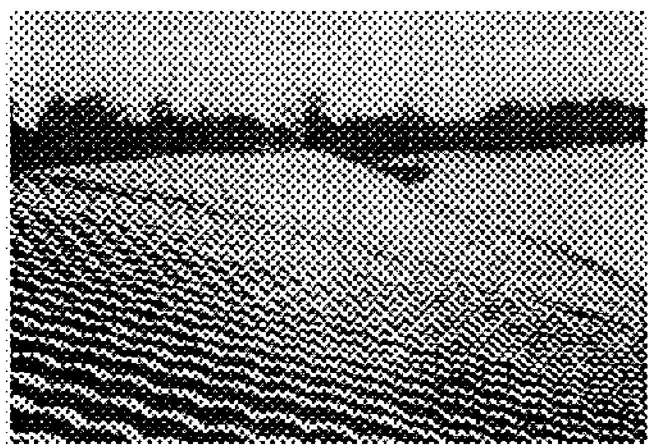


Figure B-32. Fabriform revetment, location unknown

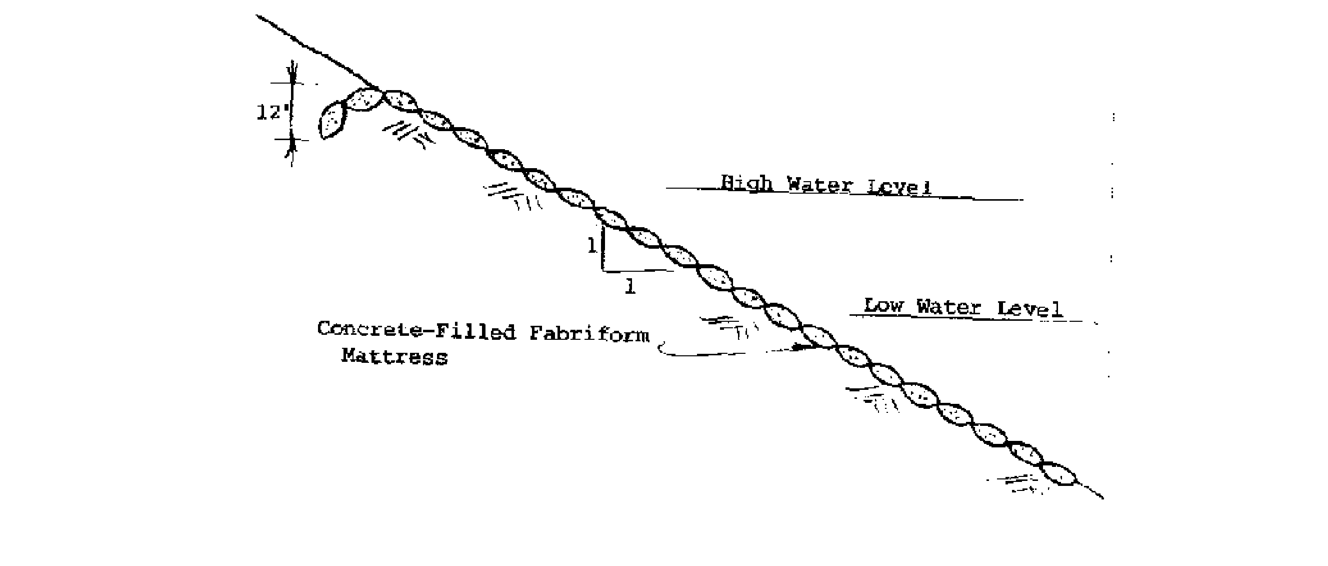


Figure B-33. Fabriform revetment cross section

masses that are joined together, there is a danger of cracking and breaking of the mat under differential settlement. Also, the mats may be damaged by heavy floating debris.

B-19. Bags

a. Blanket revetment. One or two layers of bags placed directly on a slope are suitable for temporary, emergency, or other short-term protection. The smooth, rounded contours of the bags present an interlocking problem, and they slide easily. For improved stability, the bags should be kept underfilled to create a flatter shape with a greater surface contact area.

b. Stacked-bag revetment. This type of structure consists of bags that are stacked pyramid-fashion at the base of a slope or bluff. The long axes of the bags should be parallel to shore, and the joints should be offset as in brickwork. Grout or concrete-filled bags can be further stabilized with steel rods driven through the bags. The same precautions about underfilling the bags for greater stability should be observed with this kind of structure. In addition, sufficient space should be provided between the structure and the bluff to preclude damages in the event of bluff slumping and to provide an apron to absorb wave energy that overtops the structure thereby protecting the toe of the bank from scour.

c. Design factors (estimated).

(1) Zero-damage wave heights:

1.5 ft for small bag blankets.
2.0 ft for large bag blankets.

2.0 ft for small bag stacks.
3.0 ft for large bag stacks.

(2) Wave runup potential for:

Blankets is 90 percent of smooth slope runup.

Stacked bags is 80 percent of smooth slope runup.

(3) Wave reflection potential is high.

d. Prototype installation.

(1) General description (Figures B-34 and B-35). An excellent example of a bag revetment is one constructed in June 1978 at Oak Harbor, WA, on Puget Sound. The structure was built in two halves, one using ready-mix concrete in burlap bags and the other using a commonly available dry sand-cement mix in paper sacks. The dry-mix sacks in each tier were systematically punctured with pitch forks and flooded with fresh water from a

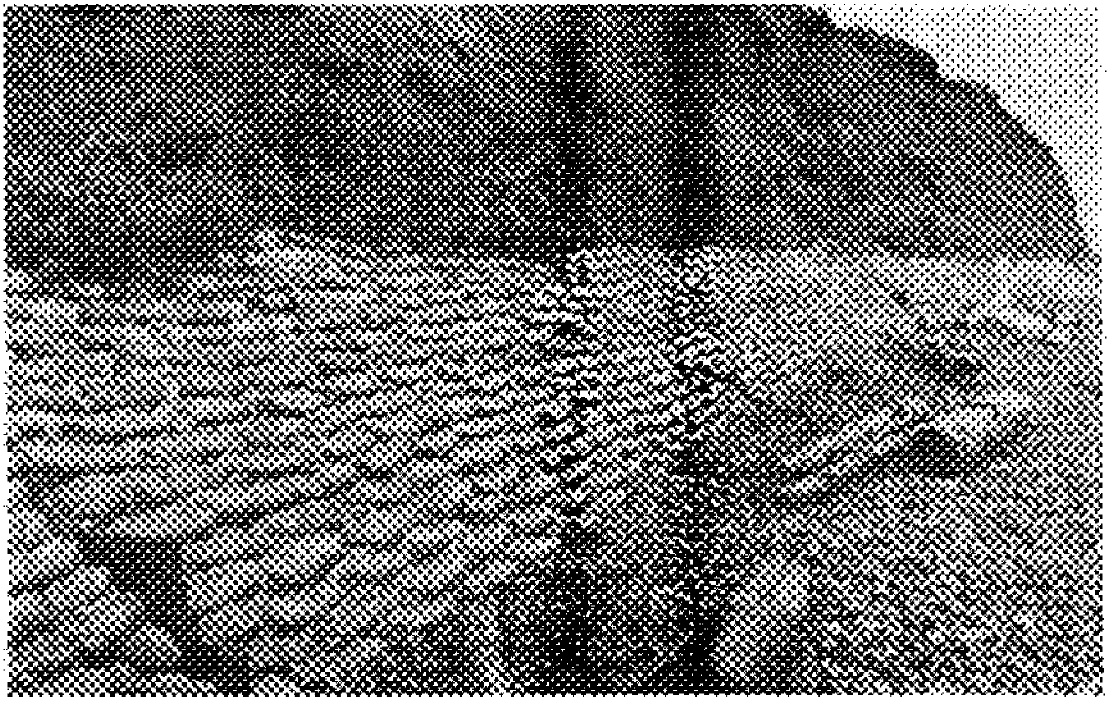


Figure B-34. Bag revetment at Oak Harbor, WA

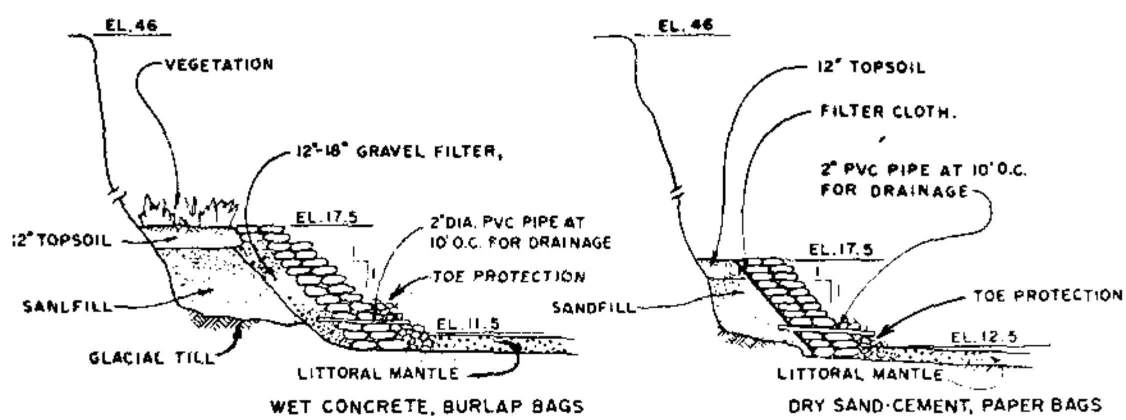


Figure B-35. Bag revetment cross section

garden hose before the next tier was placed. Note from the cross sections that a gravel filter was used behind the burlap bags and a filter cloth behind the paper sacks. Also, PVC drain pipes were provided at 10-ft centers for hydrostatic pressure relief. The landward ends of these pipes were wrapped with filter cloth to prevent passage of fines through the drain pipes.

(2) Performance. Several severe storms have struck the site with breaking wave heights of 3.5 ft or more.

Neither structure suffered significant damages as a result of these storms, but the toe rock was displaced. This displacement eventually led to a partial unravelling of the burlap bag structure proceeding from the toe at a point of especially severe wave attack. The burlap bags, however, did appear to nest better than the paper sacks, and the ready-mix concrete will probably provide a longer service life than the dry sand-cement mix. Overall, however, the bag revetments proved to be an excellent and economical solution at this site.

B-20. Gabions

a. General. Gabions are rectangular baskets or mattresses made of galvanized, and sometimes also PVC-coated, steel wire in a hexagonal mesh. Subdivided into approximately equally sized cells, standard gabion baskets are 3 ft wide and available in lengths of 6, 9, and 12 ft and thicknesses of 1, 1.5, and 3 ft. Mattresses are either 9 or 12 in. thick. The standard baskets are generally preferred over mattresses because they are fabricated of heavier wire (approximately 11 gauge versus approximately 13-1/2 gauge). At the jobsite, the baskets are unfolded and assembled by lacing the edges together with steel wire. The individual baskets are then wired together and filled with 4- to 8-in.-diam stone. The lids are finally closed and laced to the baskets, forming a large, heavy mass.

b. Advantages. One advantage of a gabion structure is that it can be built without heavy equipment. Gabions are flexible and can maintain their function even if the foundation settles. They can be repaired by opening the baskets, refilling them, and then wiring them shut again. They can also be repaired with shotcrete, although care must be taken to ensure relief of hydrostatic pressures.

c. Disadvantages. One disadvantage of a gabion structure is that the baskets may be opened by wave action. Also, since structural performance depends on the continuity of the wire mesh, abrasion and damage to the PVC coating can lead to rapid corrosion of the wire and failure of the baskets. For that reason, the baskets should be tightly packed to minimize movement of the interior stone and subsequent damage to the wire. Rusted and broken wire baskets also pose a safety hazard. Gabion structures require periodic inspections so that repairs are made before serious damage occurs.

d. Design precautions. To ensure best performance, use properly sized filler rock. Interior liners or sandbags to contain smaller sized material are not recommended. The baskets should be filled tightly to prevent movement of the stone, and they should be refilled as necessary to maintain tight packing. Gabions should not be used where bombardment by waterborne debris or cobbles is present or where foot traffic across them is expected. Baskets must be filled in place to allow them to be laced to adjacent units prior to filling.

e. Design factors (estimated).

(1) Zero-damage wave height is 5 ft.

(2) Wave runup potential is 80 percent of smooth slope runup.

(3) Wave reflection potential is high.

f. Prototype installation (Figures B-36 and B-37). A gabion revetment was constructed at Oak Harbor, WA, in June 1978 (final report on the Shoreline Erosion Control Demonstration Program). Note that half of the revetment was placed on a gravel filter, and half was placed on filter cloth. The structure weathered several storms in the ensuing 2 years and suffered little damage attributable to the gabions themselves (backfill was lost in several areas where no filter had been placed). Performance was adequate at this site where breaking wave heights probably did not exceed 3.5 to 4.0 ft.

B-21. Steel Fuel Barrels

a. General. This type of revetment is limited to remote areas where there is an abundance of used fuel barrels of little salvageable value. Due to rapid corrosion of the barrels in warm water, the system is reliable only in Arctic regions. The barrels should be completely filled with coarse granular material to preclude damage by floe ice and debris, and the critical seaward barrels should be capped with concrete. Also, partial burial of the barrels increases stability.

b. Design factors (estimated).

(1) Zero-damage wave height is 3 ft.

(2) Wave runup potential is 80 percent of smooth slope runup.

(3) Wave reflection potential is medium to high.

c. Prototype installation (Figures B-38 and B-39). A barrel revetment was constructed at Kotzebue, AK, off the Arctic Ocean during the summers of 1978 and 1979

Figure B-36. Gabion revetment, Oak Harbor, WA

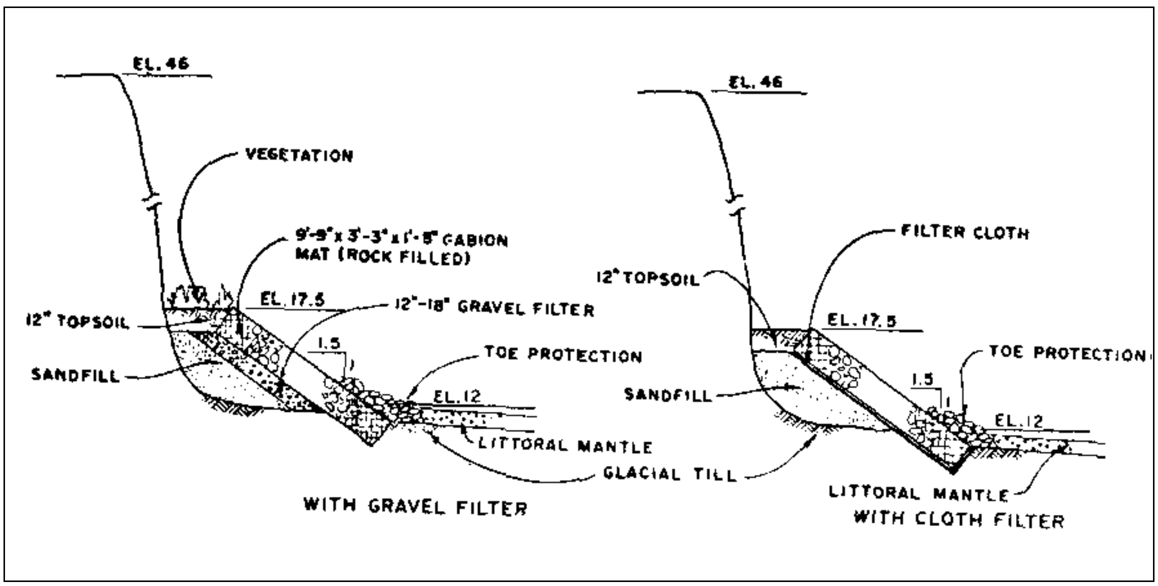


Figure B-37. Gabion revetment cross section

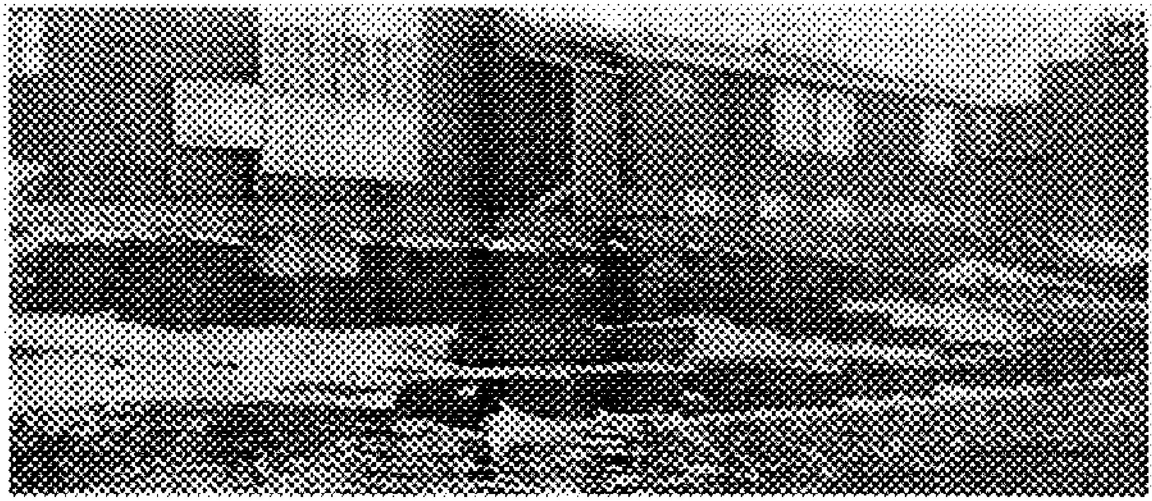


Figure B-38. Steel fuel barrel revetment, Kotzebue, AK

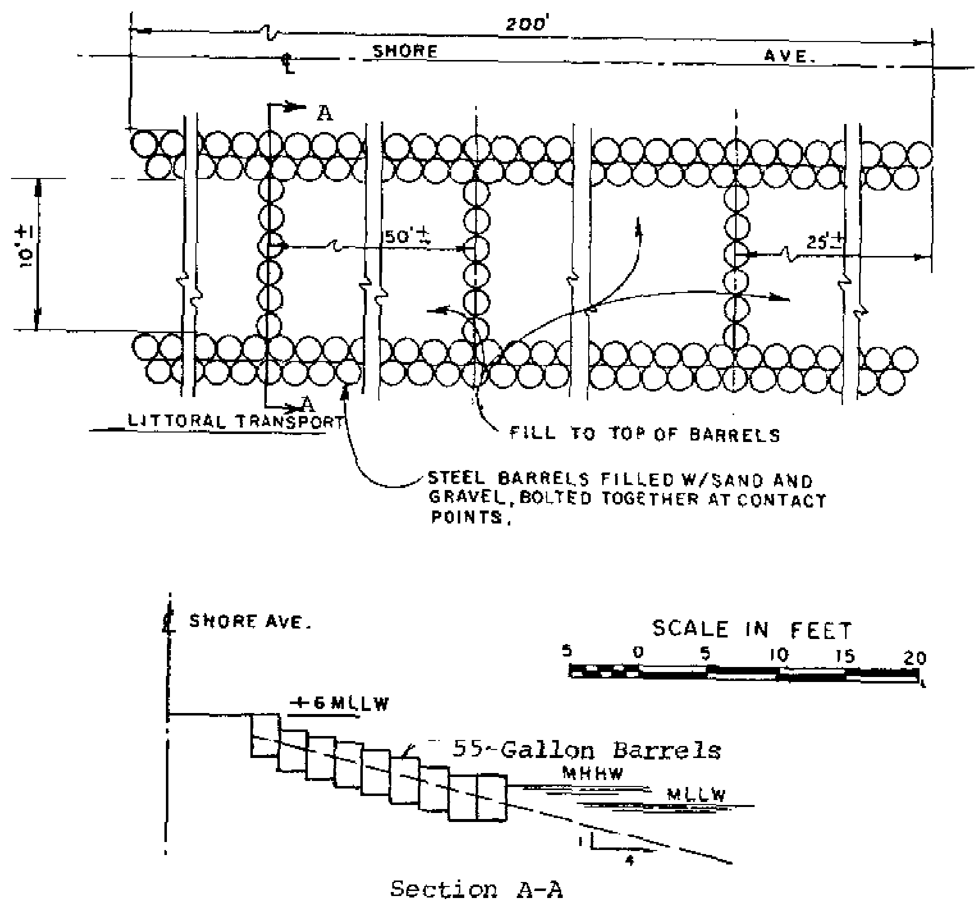


Figure B-39. Steel fuel barrel revetment plan and cross section (final report on Shoreline Erosion Control Demonstration Program). Performance was acceptable, although wave-driven ice floes damaged some of the barrels at the seaward end of the structure. Gravel fill within the barrels limited the damages, but retention of this fill was difficult without the use of expensive concrete caps or other positive means.

B-22. Fabric

a. General. Revetments using filter cloth or other fabrics as the slope's armor layer have not been successful. They do have some potential, however, as expedient, emergency devices when speed of construction or lack of suitable armor materials necessitate their use. The fabric can be used alone, or it can be combined with some form of ballast to add stability.

b. Design factors (estimated).

(1) Zero-damage wave height is 0.5 to 1 ft.

(2) Wave runup potential is 100 percent of smooth slope runup.

(3) Wave reflection potential is high.

c. Prototype installations (Figures B-40 and B-41). Two filter cloth revetments that have been documented were built at Fontainebleau State Park, LA, in the fall of 1979 (final report on Shoreline Erosion Control Demonstration Program). The first utilized a filter cloth with large pre-sewn ballast pockets to help hold the filter cloth panel in place. The outer rows of pockets were filled with bags of sand-cement and the interior pockets were filled with shell. The entire cloth was covered with 6 in. of shell and then with 6 in. of topsoil which was seeded with Bermuda grass and fertilized. The other revetment was constructed with the same cloth but with pre-sewn loops to which ballast (115-lb blocks) could be attached to anchor the cloth. Instead of using the loops, however, the blocks were anchored to the cloth with galvanized iron pins driven through the holes in the blocks. Performance of both revetments was poor, and neither form of anchoring was sufficient for stability for a period longer than a few months.

B-23. Concrete Slabs

a. General. Large concrete slabs salvaged from demolition work have often been used for shore protection. Placed directly on a slope, they provide a massive, heavy structure that is not easily moved by wave action. Failures have been numerous, however, usually due to improper provision for filtering, inadequate toe protection, and lack of flank protection.

b. Design factors (estimated).

(1) Zero-damage wave height is 1 to 5 ft depending on the thickness of the slabs.

(2) Wave runup potential is 100 percent of smooth slope runup.

(3) Wave reflection potential is high.

c. Prototype installation (Figures B-42 and B-43). A concrete slab revetment constructed at Alameda, CA, in November 1978, is illustrative of the problems commonly experienced with this kind of structure (final report on Shoreline Erosion Control Demonstration Program). The structure was placed on a sand fill at a 1-on-0.6 slope with an underlying nonwoven filter cloth. The slabs, obtained from a building demolition site, were hoisted into place by crane; and one slab was cracked during this operation. The structure failed under wave action because of inadequate toe protection, flanking, failure of the filter cloth under the shifting slabs, and inherent instability of the underlying 60-deg slope.

B-24. Soil Cement

a. General. Soil cement is a mixture of portland cement, water, and soil. When compacted while moist, it forms a hard, durable material with properties similar to concrete and rock. A typical mixture may contain 7 to 14 percent portland cement and 10 percent water by weight of dry soil. Use of soil cement in shore protection is discussed in Wilder and Dinchak (1979).

b. Design factors.

(1) Zero-damage wave height depends on layer thickness and quality control during construction up to an estimated 10-ft maximum.

(2) Wave runup potential is 80 to 90 percent of smooth slope runup (Stoa 1979).

(3) Wave reflection potential is estimated to be high.

c. Prototype installation (Figures B-44 and B-45). One of the oldest known soil cement installations in the United States is a test section on the southeast shore of

Figure B-40. Fabric revetments, Fontainebleaus State Park, LA

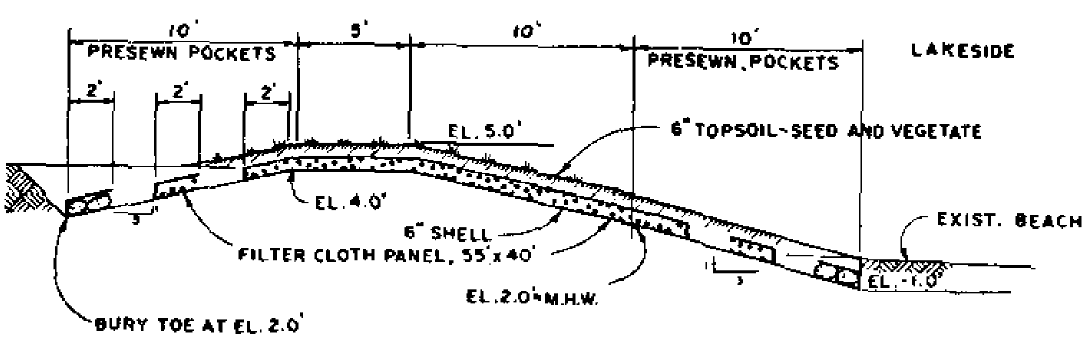


Figure B-41. Fabric revetment cross section

Bonny Reservoir in eastern Colorado. It consists of a series of 6-in.-thick by 7-ft-wide horizontal layers of soil cement with about a 1-on-2 slope to the exposed stairstep face. Constructed in 1951, it remains in good structural condition. At three sites on the north shore of the Gaspe Peninsula, Quebec, 6,000 ft of soil cement revetments, constructed in stairstep fashion, and having 2.5-ft thickness normal to the slope, have successfully withstood repeated attacks by waves up to 10 ft high (measured offshore) since their completion in 1975 (Wilder and Dinchak 1979).

B-25. Tire Mattresses

a. General. Tire mattresses consist of loose or connected scrap tires placed on a filter and filled with a sand-cement or ready-mix concrete ballast. Such structures can be durable, flexible, and inexpensive provided the weight of the filled tires provides adequate stability.

b. Design factors (estimated).

(1) Zero-damage wave height is 1 ft.

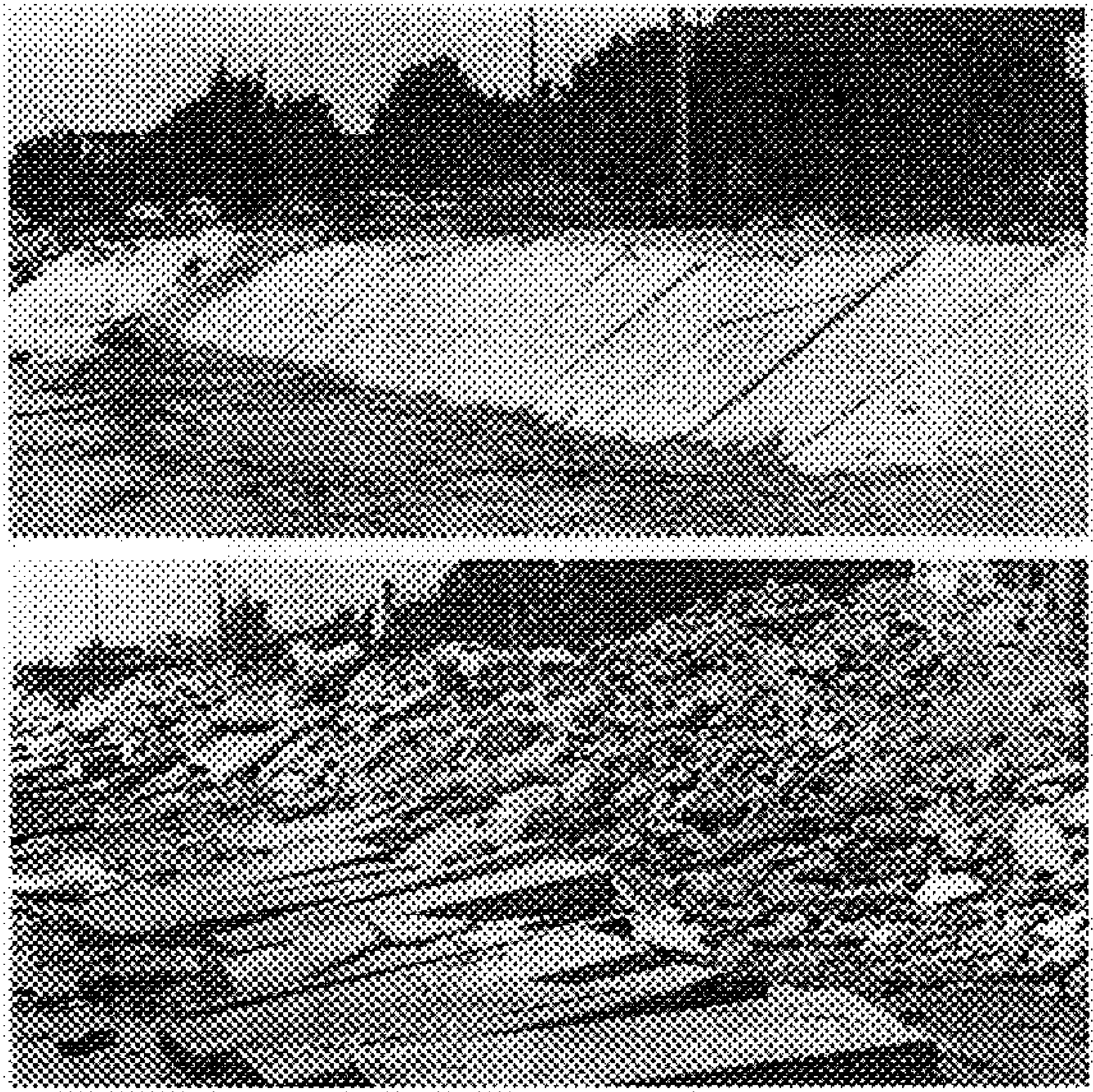


Figure B-42. Concrete slab revetment, Alameda, CA

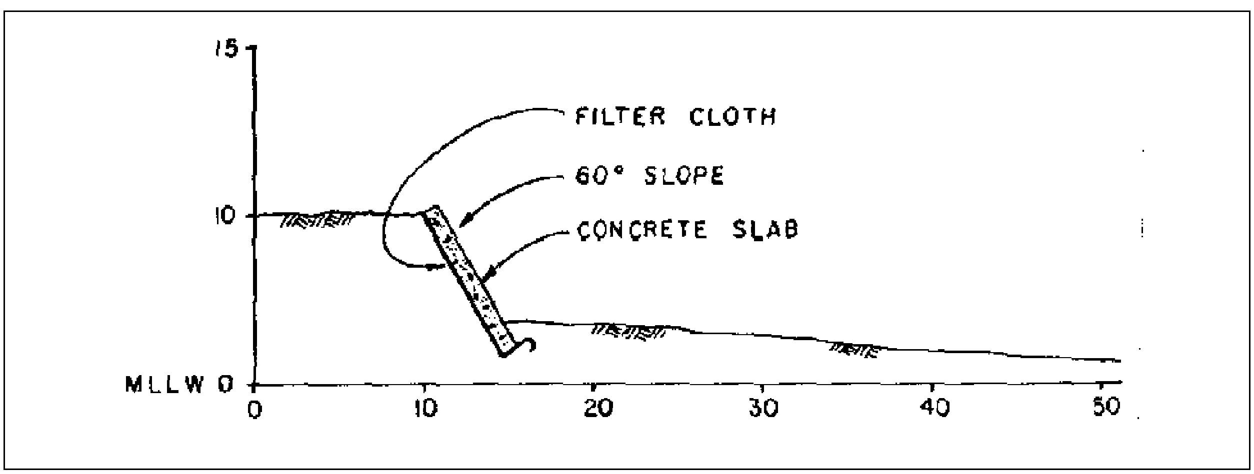


Figure B-43. Concrete slab revetment cross section

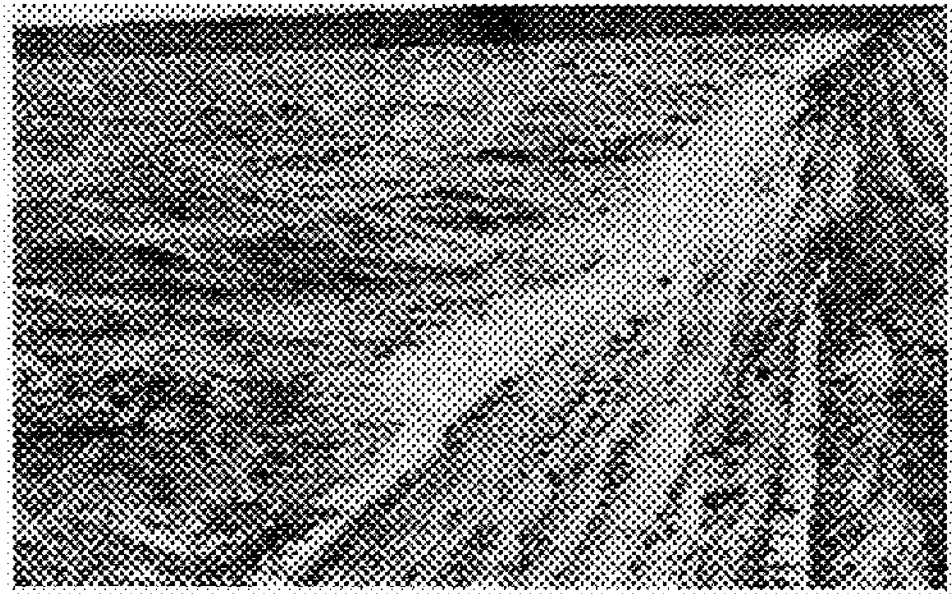


Figure B-44. Soil cement revetment, Bonny Dam, CO

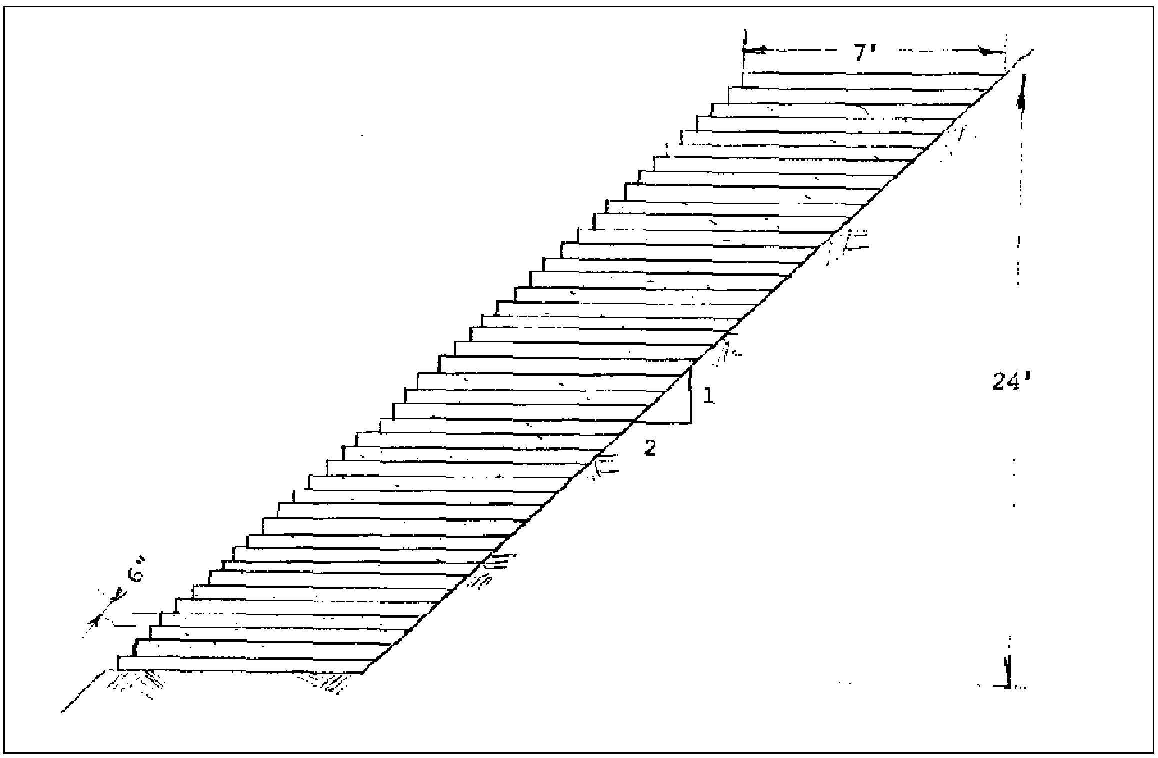


Figure B-45. Soil cement revetment cross section

(2) Wave runup potential is 90 percent of smooth slope runup.

(3) Wave reflection potential is high.

c. Prototype installation (Figures B-46 and B-47). A prototype structure was built in October 1979, at Fontainebleau State Park, LA (final report on Shoreline

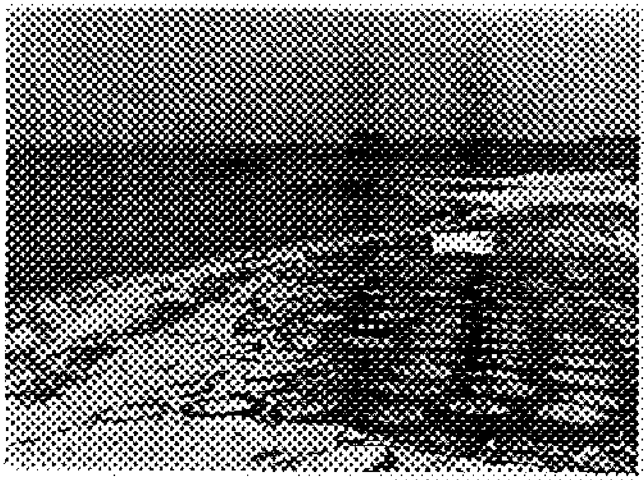


Figure B-46. Tire mattress revetment, Fontainebleau State Park, LA

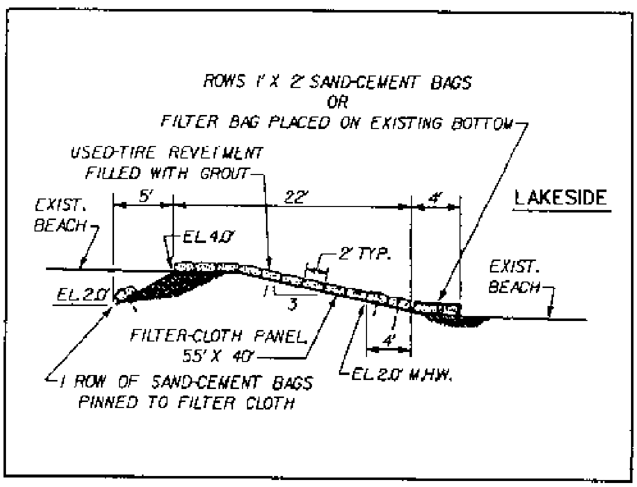


Figure B-47. Tire mattress revetment cross section

Erosion Control Demonstration Program). A filter cloth was placed on a prepared 1-on-3 slope, and two rows of sand-cement bags were placed along the lakeward edge to act as toe protection. The filter cloth was lapped over the bags at the toe, and the first row of tires was placed on this overlap (Dutch toe method). The tires were filled with a dry sand-cement mixture, and the revetment was completed with another row of bags at the crest. The structure remained stable until April 1980 when a storm displaced about 50 percent of the tires, although the structure still continued to function after that. One contributing factor to the failure was the use of dry sand-cement which led to incomplete filling of the tires and significantly reduced the weight per unit.

B-26. Landing Mats

a. General. Mo-Mat is one form of landing mat consisting of 0.625-in.-thick fiberglass molded into a waffle pattern with a weight of about 1 lb/ft^2. It may be used as revetment armoring in mild wave climates, given adequate toe protection and filtering, along with a suitable method of strongly anchoring the mats to the subgrade.

b. Design factors (estimated).

(1) Zero-damage wave height depends on strength of anchoring system and is probably in the range of 1 to 2 ft.

(2) Wave runup potential is 100 percent of smooth slope runup.

(3) Wave reflection potential is high.

c. Prototype installations. Unknown. A possible section is shown in Figure B-48.

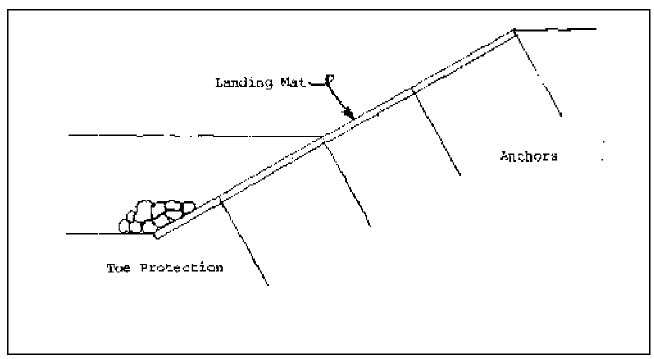


Figure B-48. Landing mat revetment

B-27. Windrows

a. General. Windrows provide an alternative method of utilizing rock for slope protection. Instead of incurring the expense of constructing a formal revetment structure, the rock can be stockpiled at the top of a slope to be released when erosion causes the bank to retreat. As an alternative, the rock can be placed in a trench at the top of the bank and covered with soil and seed. In either case, the cost is probably less than with a formal revetment. The obvious disadvantage is that the random launching of this material down the slope probably does not allow for formation of an adequate filter layer beneath the larger armor stones. Presumably, if a large quantity of well-graded stone were stockpiled in the windrow, natural sorting processes would eventually lead to development of an adequate filter given sufficient time and material. This method could be used at a site where some bank recession is acceptable before the windrow revetment is needed.

b. Design factors.

(1) Zero-damage wave height is a function of stone size and gradation.

(2) Wave runup potential is estimated to be as low as 50 percent of smooth slope runup.

(3) Wave reflection potential is low.

c. Prototype installations. Actual sites are unknown, but the method has apparently received widespread use for riverbank protection in some areas of the country. A possible section is shown in Figure B-49.

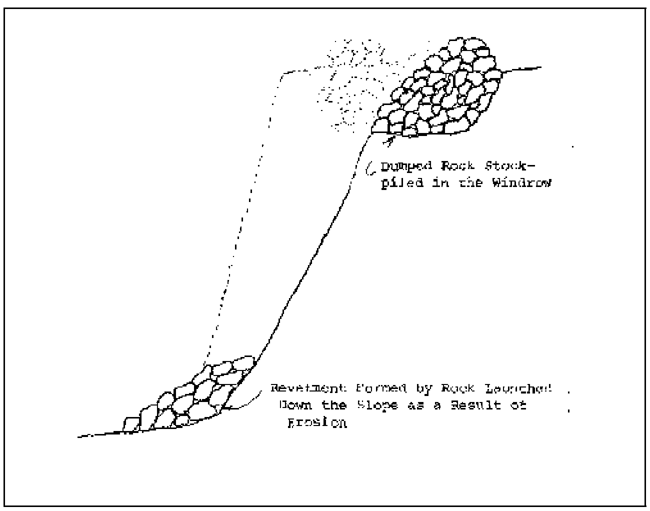


Figure B-49. Windrow revetment

B-28. Vegetation

a. General. Vegetation can be a highly effective shore protection method when used under the right conditions. Marsh grasses can be used as a buffer zone to dissipate incoming wave energy, and other species can be used in the area above the intertidal zone to directly protect and stabilize the shoreline. The appropriate species to use varies throughout the country. Smooth cordgrass (*Spartina alterniflora*) is excellent for marsh plantings in many areas. This is not true of the Great Lakes, however, where neither this nor other marsh species have been particularly successful for stabilizing shorelines. The best species for planting above the intertidal zone vary throughout the country, and only those that are well adapted to local conditions should be used.

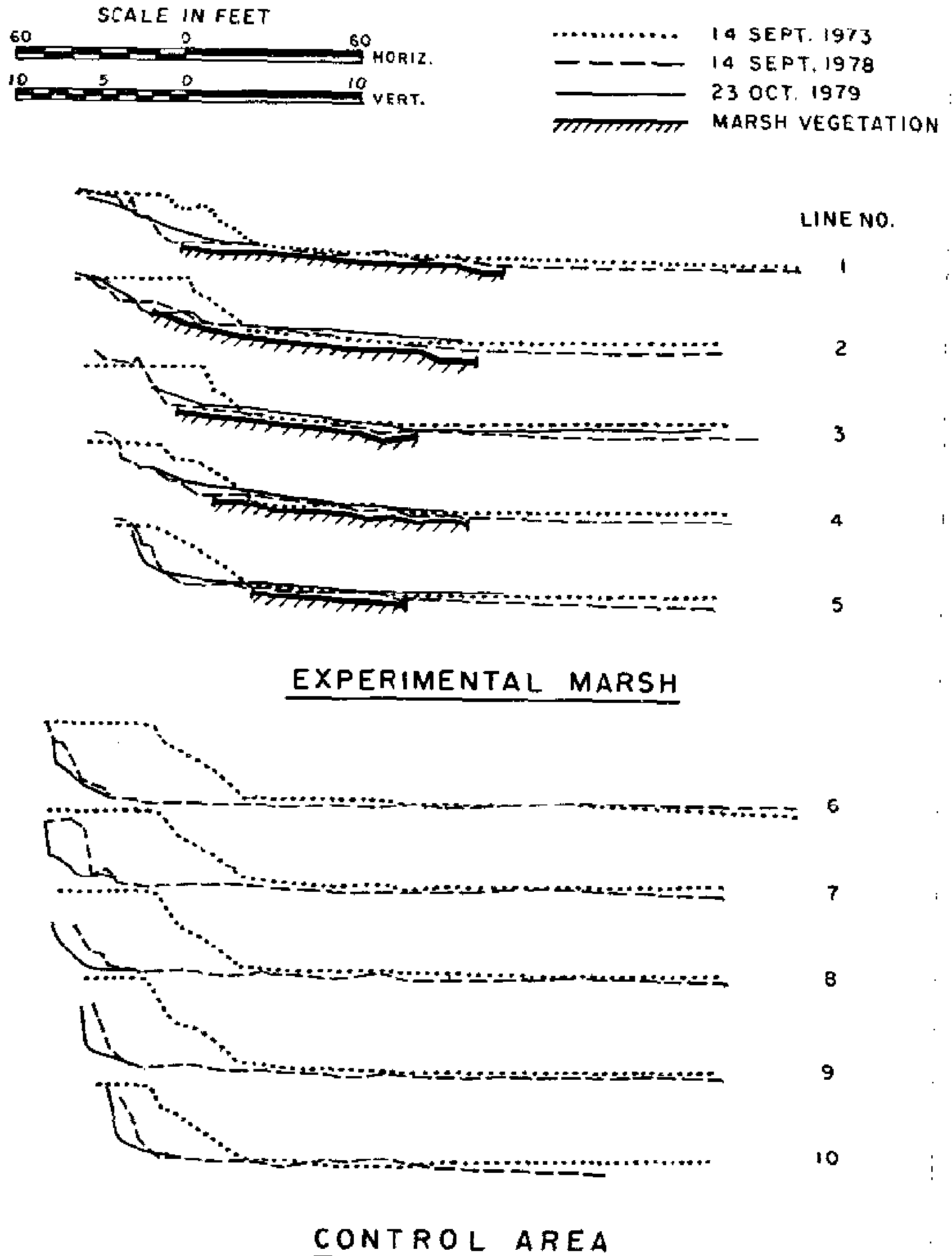
b. Design factors.

(1) Zero-damage wave height is estimated to be less than 1 ft although some installations survive in higher energy if they can become established during lower energy regimes.

(2) Wave runup potential is low for well-established plantings.

(3) Wave reflection potential is low for well-established plantings.

c. Prototype installations (Figure B-50). Four species of marsh plants, narrow- and broad-leaved cattails (*Typha augustifolia* and *T. latifolia*), giant reed (*Phragmites australis*), smooth cordgrass (*Spartina alterniflora*), and black needle rush (*Juncus roemerianus*) were planted at a site on Currituck Sound, NC, in 1973 (final report on Shoreline Erosion Control Demonstration Program). Profiles taken through the site and through an unplanted control area revealed that the erosion rate decreased as the vegetation became established in the planted area. By 1979 the control area had continued to erode at about 8.8 ft per year, while the protected area was stable and even accreting slightly.



Comparative profiles, Duck, North Carolina.

Figure B-50. Protective vegetative plantings